INDIAN METEOROLOGIST'S VADE-MECUM.

PART I:

INSTRUCTIONS

TO

METEOROLOGICAL OBSERVERS IN INDIA.

INSTRUCTIONS

TO

METEOROLOGICAL OBSERVERS IN INDIA,

BEING THE FIRST PART OF

THE INDIAN METEOROLOGIST'S VADE-MECUM.

BY

HENRY F. BLANFORD,

METEOROLOGICAL REPORTER TO THE GOVERNMENT OF INDIA.

Printed for the use of the Meteorological Department
by the orders of Government.

CALCUTTA:

OFFICE OF THE SUPERINTENDENT OF GOVERNMENT PRINTING.

1876.

1881, July 12.
Gift of
The Record Dept.
India Office,
London.
(Pt. I., II.)

CALCUTTA:
PRINTED BY THE SUPERINTENDENT OF GOVERNMENT PRINTING,
8, HASTINGS STREET.

CONTENTS OF PART I.

CORRIGENDA AND ADDENDA

IN THE

INSTRUCTIONS TO OBSERVERS.

Page 59, in the list of symbols and weather initials, *insert*—

● . . . *r*. . . . Continued rain.

„ 79, line 12, *for* first and fifteenth, *read* first and sixteenth, *and for* February the fourteenth, *read* February the fifteenth.

„ 92, line 8, *for* 15th, *read* 16th.

INDIAN METEOROLOGIST'S VADE-MECUM.

PART I:

INSTRUCTIONS TO OBSERVERS.

INTRODUCTION.

THE object of meteorological observation is to collect facts for studying the physical changes of the atmosphere, in order that we may gain therefrom a knowledge of their causes and their laws. This is a branch of physics, and requires therefore the same care, and the same precautions, that are demanded in all experiments and observations undertaken for the discovery of physical laws. It might be thought that so obvious an inference would scarcely need insisting on; and yet it is unquestionable that very many of those persons who keep a regular register of the readings of meteorological instruments, and who even devote much time and attention to the occupation, practically ignore it; and incur much disappointment when, perhaps after many years' assiduous labour, they are told by some one who has vainly sought to turn their registers to useful account, that, owing to the neglect of a few simple precautions, the whole of those results are of little or no value. A barometer and a thermometer are instruments of simple construction, and any person of ordinary intelligence may be taught in the course of a few minutes how to read them accurately. But it is of little use to be able to read them, unless we know exactly what is the physical meaning of the readings we record; in other words, unless we know how that particular condition of the instrument which is expressed by each reading has been brought about; and (since, in all cases, many causes have been at work to produce it, while we want to measure only one of them,) unless we can eliminate all that is foreign to our purpose, and so ascertain that one measure truthfully or within assignable limits of error. The best known of all meteorological instruments, the thermometer, will serve to illustrate these remarks. Take any four thermometers of different kinds and dimensions, and hang them, side by side, on a wall in a verandah or well-ventilated room. They will probably be found to differ from one-tenth of a degree to a degree in their readings, sometimes as much as two or three degrees. These differences may arise either from the fact that

the thermometers are not equally sensitive, or from errors in their graduation, such as affect almost all instruments more or less. If they arise from the first cause, they will disappear from the mean of a large number of readings, taken in about equal proportions with the temperature rising and falling. But if from the latter, however small they may be, they will affect to their full extent all registers of their readings, however extensive and varied, and all mean values computed therefrom; and to that extent they will falsify the required records; yet in India very few observers take the trouble to ascertain the errors of their instruments, and some who know them are too careless or too ignorant to correct them.

Having by due comparison determined the inherent errors of the instruments, so that, by applying corrections, their readings may be reduced to a common standard, suspend one of them in a well-ventilated room, another in a verandah, a third beneath a thatched shed open all round, and a fourth on an open stand, such as is recommended by Colonel James or Mr. Glaisher; all, of course, shaded from the sun. In these several positions let readings be taken in fine, dry weather, a few minutes before sunrise and again about three in the afternoon. In the first set of readings, the thermometer on the open stand will probably be one or two degrees lower than any of the others; next above it, will be that in the shed; next, that in the verandah; and highest of all will be that in the room. The afternoon readings will differ quite as much, but in the reverse order, the thermometer on the stand being highest, that in the room lowest; and the extreme difference may amount to as much as 5 or 6 degrees. Now, all these various kinds of exposure are practised, and yet it is seldom stated in the published returns which of them has been adopted. Such returns are, of course, not comparable with each other, and, if the facts are unknown, no one can make any use of them.

Lastly, it is not infrequent to find in the registers of temperature published in official reports, not the actual observations, but certain values which are called 'means.' But it is very rarely stated how these means have been computed. One person reads an ordinary thermometer at 10 A. M. and 4 P. M., and gives the average of the two readings; another gives the average of his maximum and minimum; and in some registers which lately came under my notice, this mean temperature was obtained by adding together the readings of a minimum and maximum thermometer recorded and re-set both at 10 A. M. and 4 P. M., and dividing by four. This really amounted to giving, as the mean temperature of the day, the average of the highest and lowest temperatures, of 10 in the morning and of 4 o'clock of the previous afternoon. The proper meaning of the term 'mean' will be explained further on; but it is clear that the results of the above three methods will all be different, and, indeed, only one of them even approximates to what the term is understood to imply.

In order, then, that a meteorological register may be of any value, the work of observation must be conducted intelligently, and with a number of precautions which can be appreciated only by trained physicists. Honesty—not always, alas! to be counted on—is, of course, a *sine quâ non*. But neither honesty nor zeal will suffice without knowledge. Such knowledge it is the object of this little treatise to convey, as far as is consistent with brevity, by means of short explanations and rules founded thereon. A little book on a somewhat similar plan, printed in 1868, for the guidance of observers in Bengal and elsewhere, has been found of much use in facilitating the meteorological work. This is now out of print, and, instead of simply re-printing it, I have considered it better to re-write the instructions, omitting some items that are unnecessary or obsolete, and embodying such additional matter as has been suggested by the increased experience gained during the last seven years. The first part of the book being intended simply as a guide to those who keep a meteorological register, I have not entered on the subject of meteorology as a science, further than is necessary for the due understanding of the methods of recording observations. In the second part I have entered upon some of the more important laws of pneumatics and thermotics that regulate meteorological phenomena; and I have given such a sketch of what is known of Indian meteorology as will serve as a groundwork of information for those who may desire to engage in the further study of the phenomena around us. This seems a necessary addition to the original work, since, in many respects, phenomena which are here familiar and striking, are but of subordinate importance in extratropical countries, and *vice versâ*. There are several excellent manuals to which persons may refer who desire to understand something of the science in its European aspects. Among the best are Buchan's Handy-book, and Introductory Text Book, Loomis' Treatise, and Herschell's Meteorology, which, though written many years ago, and therefore in some few respects requiring revision, is still unequalled for thoroughness in a physical point of view. For readers of German, Mohn's Hand-book is an admirable recent work; and among the older works Kaemtz and Schmidt are still valuable works of reference. For a knowledge of the cotemporary progress of the science, the Journal of the Austrian Meteorological Society,[a] edited by Dr. Carl Jelinek and Dr. J. Hann, is an unrivalled source of information.

---

[a] Zeitschrift der österreichischen Gesellschaft für Meteorologie.

BAROMETER.

Object and principle.—The barometer is used to measure the pressure of the atmosphere.[a] It has many forms, but consists essentially of a vessel of mercury termed the cistern, in which is inverted a glass tube closed at top and open below, and which, before being inverted, has been entirely filled with mercury. In virtue of the law of fluid pressure, the air pressing on the mercury of the cistern can support in the tube a column of mercury, which presses on its base, with a pressure equal to that of the air on the same area of cistern surface. An air column, resting on the surface of the sea, presses equally with a column of mercury of the same diameter and about 30 inches high on an average. If, therefore, the tube be shorter than this, the barometer being at the sea level, it will remain full of mercury. But if longer, (and a barometer tube always is longer than 30 inches,) the mercury will fall to about that height, leaving a vacuum in the upper part of the tube which is known as the Torricellian vacuum. As the pressure of the air varies, so does the height of the barometric column vary; since, the greater the pressure of the atmosphere, the higher the column it supports in the tube.

2. Verticality.—It is to be observed that the height of the column, here referred to, is the *distance* between the *surface of the mercury in the cistern* and that of the top of the column *measured on a vertical line.* A barometer must, therefore, be perfectly vertical by the plumb line, or its length, as read off on the scale attached to it, will be invariably greater than its vertical height. If a barometer is suspended by a ring at the top, or, as marine barometers usually are, from a gimbal considerably above the centre of gravity of the instrument, it will take the vertical position at once. But if it is fixed at top and bottom to brackets projecting from a backboard (Fig. 2), its verticality must be adjusted by a plumb line.

---

[a] Much confused and erroneous reasoning has arisen from persons failing to distinguish between the *pressure* of the atmosphere and its *weight.* The barometer measures its *pressure;* and this is equal to its *weight* (or, more correctly, *static* pressure) only when the air is at perfect rest and undergoing no change of temperature; a condition which, of course, is never completely fulfilled. Probably, on an average, the actual weight of the superincumbent atmosphere is most nearly shewn by its pressure about 4 or 5 in the afternoon and between 3 and 4 in the early morning: but the justice of this view depends on what is the true explanation of the diurnal oscillation of pressure; and it may be said truly that we know nothing accurately of the weight of the atmosphere, but only that it cannot be very different from the average pressure. It is best, in speaking of the barometric condition of the atmosphere, to avoid the use of the term 'weight' altogether, unless there be special reasons for referring to it.

3. Adjustment of Levels.—It has been said that the height to be measured is that between the *surface* of the mercury in the cistern and the top of the column. Now, the top of the column is not flat, but a curved, convex surface (except in very large tubes). The line which bounds the contact of the mercury with the glass is appreciably lower than the real surface, and must not be taken as the measure of the height. This is very often done by persons unacquainted with the proper use of the instrument, but readings so taken are of no value for any scientific purpose. *The measurement must always be taken from the highest point of the curve.* This is effected by means of the vernier, which will presently be described.

Since the quantity of mercury in a barometer is constant, if the column rises in consequence of increased atmospheric pressure, some mercury must enter the tube from the cistern, and the level of the latter falls. The total change, therefore, is made up of the rise of the column added to the fall of the cistern level, and this is measured by various contrivances.

4. Fortin's Principle.—By adjusting the cistern level to a constant point, which is the zero of the scale. This is called Fortin's principle, and is that most commonly adopted. Barometers constructed on this principle have the bottom of the cistern formed by a bag of leather (see Fig. 1) or a solid, but movable piston. A screw, provided with a milled head, projects from the bottom of the brass casing which encloses the cistern. By turning this screw, the bag or piston is raised or lowered, decreasing or increasing the capacity of the cistern, and, as a consequence, raising or lowering the mercury. The upper part of the cistern is of glass, which renders visible the surface of the mercury, and also a pointed or a chisel-shaped stud which projects from the cover, and the lower end of which is the zero point of the scale for measuring the column.

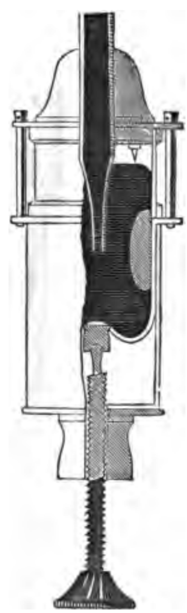

Figure 1. Barometer cistern on Fortin's principle, partly in section to shew the construction.

To adjust the cistern level, first lower the mercury, by turning the screw until the surface is well below the stud. Then raise it again very slowly until it just touches the point of the stud without being indented. If the surface of the mercury is bright, the moment of contact may be

judged very accurately, by watching the apparent approach of the point and its reflection until they meet. If the point appears to indent the mercury surface, the latter is too high and must be lowered.

If the stud have a chisel edge, the adjustment may be determined by so screening the cistern at the side, that the ivory stud is well shaded; and keeping the eye on the level of the mercury surface, looking beneath the knife edge towards the light, or, better, towards a piece of paper or other white surface behind. A streak of light is then seen below the stud until the instant that contact is made, when it at once disappears. The degree of accuracy with which the adjustment may be made very much depends on the skilful arrangement of the light (see § 17).

Figure 2. Newman's Standard barometer.

5. Newman's Standard.—In this form of barometer, the cistern capacity is constant, but the scale is movable. The graduated part of the scale does not exceed a few inches (26 to 31 inches) opposite the upper part of the column, and a metal rod, attached to the back of the scale and concealed in the hollow frame of the instrument, terminates below in an ivory point (9 in Fig. 2), which is the zero of the scale graduation; the rod and scale are raised and lowered by means of a pinion at the side (8), working in an endless screw, and the zero point of the scale is thus adjusted to the cistern level.

6. Double reading.—This principle is adopted in the syphon barometer, and also in some large observatory standards, and several other forms of barometer. The scale is fixed, and the cistern level cannot be adjusted; but the variation of the latter, above or below a certain fiducial level, which is the zero of the scale, is measured by a small independent scale, and this is added to, or subtracted from, the reading of the column.

7. Capacity correction.—This may be applied to any barometer, provided the internal diameter of the tube and that of the cistern, or their ratio, are accurately known; and, although its use involves a little extra trouble, it has the advantage of being less liable to error (in the case of individual readings) than any of the mechanical methods above described, the accuracy of which much depends on the observer, the state of the instrument, the arrangement of the light, &c. Nothing can be more

simple than the capacity correction both in principle and practice. Suppose both the tube and cistern of the barometer are perfectly cylindrical, the internal diameter of the former being d, that of the latter D; and let the *external* diameter of the tube, when it plunges into the mercury of the cistern be δ; then, other things remaining the same, if mercury enters the tube from the cistern, increasing the column by a height h', the fall in the cistern level will be $h'\frac{d^2}{D^2-\delta^2}$, since these heights will be inversely as the surfaces that rise and fall, or as the squares of the diameters of the tube and cistern. Suppose that, at a particular reading, H, the zero of the fixed scale is exactly coincident with the cistern surface of the mercury, and is therefore correct: this is called the *neutral point* of that instrument. If, then, we take a reading higher than H (say $H+h'$), we must add the quantity $h'\frac{d^2}{D^2-\delta^2}$. If lower than H (say $(H-h')$, we must deduct the corresponding quantity, in order to obtain the true reading. Suppose, for instance, a barometer is known to give a true reading at 29·953 (when the reading has been reduced for temperature in the manner presently to be explained). The internal diameter of the tube at the top of the column is 0·34 inch and that of the cistern 1·62 inches: the external diameter of the tube, where it enters the mercury of the cistern, is 0·30. Then, a reading which, after reduction for temperature, gives 29·764 inches, is to be corrected as follows:—

Uncorrected reading	29·764
Deduct neutral point H. . . .	29·953
Difference $h'=$	—0·189

$\frac{d^2}{D^2-\delta^2}=\frac{0\cdot34^2}{1\cdot62^2-0\cdot30^2}=0\cdot046$ nearly, and—$0\cdot189\times0\cdot046=$ —0·008694 or—0·009 nearly,

which, applied as a correction to the original reading, gives 29·764 —0·009=29·755, the true reading. The factor 0·046 is constant for the same instrument, so long as the same tube and cistern are in use. The neutral point H, is also constant, so long as there is no loss of mercury, and the relative position of the scale and other parts of the instrument are unchanged: but if any mercury is lost by leakage, the neutral point will be lowered, and if a new tube has to be fitted, both the neutral point and the factor for capacity are altered and must be redetermined.

8. **Kew principle.**—In the foregoing description it was shewn that the rise or fall of the column h', as measured on the scale, represents a larger change, *viz.*, in the example given $h'(1+\cdot046)$. If then, in such a case, the scale be so divided that each *real* inch is made to *represent* 1·046 inches, or, in other words, if the inch represented on the scale

really measures $\frac{1}{1\cdot046} = 0\cdot958$ inch only, the scale, if true at any one position of the column, will be true for all other heights, and no correction will be required, and no adjustment of the cistern or scale. On the other hand, any index error will be constant, and the same for every part of the scale. This is termed the Kew principle. Its adoption saves some trouble; but if the tube of a barometer of this construction be accidentally broken, another tube of exactly the same diameter must be substituted, or a capacity correction must be computed and applied to the readings; and the determination of this correction, in the absence of a vacuum chamber, is tedious and troublesome; especially in India.

9. Use of the vernier.—The use of the vernier is to facilitate the accurate measurement of the height of the column. Each inch on the fixed scale of a barometer is generally divided into tenths and half-tenths of an inch, written 0·1 and 0·05. If, now, a length equal to 24 or 26 of these latter sub-divisions be set off on an independent movable scale and divided into 25 parts, each of these latter sub-divisions differs from a scale sub-division by $\frac{1}{25}$th of itself, being in the one case less, in the other greater. Such a scale is called a vernier. Now, let the vernier and fixed scales be applied to each other, edge to edge, as in Figs. 3 and 4. If the first mark of the vernier coincide with a mark of the fixed scale, the last will coincide also, but no other, and in all other cases only one mark of the vernier will coincide with a scale mark. Since each vernier division is $\frac{1}{25}$th greater or less than a scale division, the number of vernier divisions between the coinciding mark and the zero of the vernier will shew how much this zero deviates from the scale mark next below it. If the vernier scale is equal to 24 sub-divisions of the fixed scale, it reads upwards in the same direction as the fixed scale (fig. 3); if to 26 divisions, it reads downwards *from its own zero* (fig. 4).

The vernier scale is usually engraved on a piece of metallic tube which may be moved up and down, either directly by hand, or by means of a pinion and rack. [10 fig. 2.] In taking a reading, the lower edge of this tube* must be made to coincide accurately with the top of the mercurial column, as shewn in the annexed woodcut, and this requires that the top of the column shall be exactly on the same level as the eye of the observer. [See fig. 5.] In this position, on looking through the tube, the lower edges of the vernier slide in front and behind will coincide. To set the vernier then, raise it a little above the top of the column, get both edges in a line with the eye, and then lower it slowly till these edges form a tangent to the topmost outline of the column, no part of it being covered. If the zero line of the vernier is the lower edge of the slide and coincides

* In some verniers which read downwards, a part of the vernier slide is cut away and the upper edge of the opening, which is frequently bevelled off, marks the zero of the vernier.

exactly with one of the fixed scale divisions, that division gives the reading. If not, take as the scale-reading the division next below the edge of the vernier, and add thereto the reading of the vernier.

The vernier bears five principal divisions, the value of each being one-fifth of the smallest *scale* division, therefore =0·01; and each of these has five sub-divisions or parts = 0·002. The annexed woodcuts will illustrate the use of the vernier. In fig. 3, the lower edge of the vernier intersects the scale above the division 29·85 and below 29·9. Write down 29·85 as the scale reading. Then, running the eye up the vernier, the third of the major divisions is seen exactly to coincide with a scale division. Its value 0·03 added to 29·85 gives 29·880, which is the exact reading.

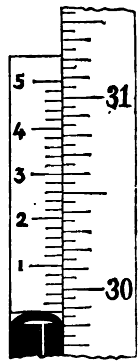

Figure 3.

In fig. 4, the lower edge of the vernier gives the scale reading 29·8, being above 29·8 and below 29·85. The vernier mark, which coincides with a scale mark, is the fourth beyond the vernier division marked 2, and has therefore the value 0·028. Adding this to 29·8, the exact reading 29·828 is obtained. Finally, if neither of the vernier marks exactly coincides with a scale mark, but one is a little above, the other a little below a scale division, ·001 is to be added to the reading of the lower of the two.

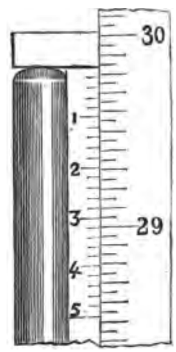

Figure 4.

As a final caution it may be mentioned that, if the barometer is so suspended that the top of the column is above the eye of the observer, or if the eye is above this level, so that the front and back edges of the vernier cannot be made to coincide, the reading will invariably be *too high*. This

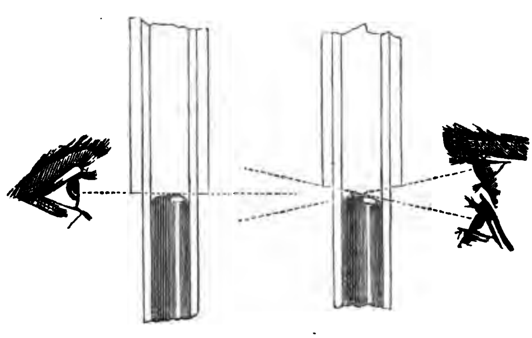

Figure 5. Effect of parallax.

is owing to parallax, and is illustrated by the accompanying figure (fig. 5). The vernier *appears* to be set when its lower edge forms an apparent tangent to the meniscus of the mercury surface. If the eye be too low, the hinder edge of the vernier slide will appear to do this before the vernier is lowered to the same level; if the eye is above the top of the column, the front edge will do so. But the front and back edges of the vernier will coincide with each other, and with the mercury surface, only when all three are on the same level. Before taking the reading, the setting of the vernier must, therefore, always be verified by moving the eye up and down; to ascertain, 1*st*, that in no position of the eye is light seen between the highest part of the surface and the edge of the vernier; and, 2*nd*, that there is one position in which the vernier conceals no part of the mercury meniscus, but only touches it.

10. Method of Reading.—First observe and write down the temperature of the thermometer attached to the barometer [11 fig. 2]. Then, (in the case of a barometer on Fortin's principle,) adjust the cistern level by turning the cistern screw till the fiducial point is quite free of the mercury, and then raising the latter till contact is made. [§ 4]. Next, adjust the vernier, by raising it till it is well above the top of the column, and then lowering it till the back and front edges coincide exactly, and form a tangent to the meniscus or curved surface of the top of the column, without covering any part of it. Note down the reading, and, having written it down, verify it by another reading of the scale and vernier. Lastly, re-observe and verify the temperature of the attached thermometer.

If the barometer be one with a narrow tube, such as a marine or mountain barometer which acts slowly, the tube (or scale) should be gently tapped with the finger-tips before setting the vernier, and again after the first reading, when the vernier should be re-set. This should be repeated till further tapping produces no further change in the reading.

11. Capillarity and Friction.—The reading of the barometer does not give at once the true pressure of the air. The mercury has no such attraction for glass as water has, and does not wet it; and in rising in a glass tube, it has to overcome a resistance due to the cohesion of the mercury, which prevents its reaching the full height at which its weight alone would counterbalance the atmospheric pressure. This deficiency is the *greater* the *smaller* the bore of the tube; and conversely, becomes less as the diameter of the tube is greater. The deficiency is constant for the same tube, and can therefore be expressed by a number which holds good for all readings of that tube. This number is termed the *capillarity correction*, and is often engraved on the brass scale of the barometer. It is to be *added* to the reading. In small tubes, the deficiency is always greater when the barometer is rising than when it is falling. This difference is owing to friction.

12. Index error.—Sometimes the capillarity correction is not given separately, but is combined with another constant correction, *viz.*, that of the scale. This correction is always small in barometers of modern manufacture by good makers. It is for the slight error of the graduation. The lines marked on the scale *should* represent standard inches when the brass of the scale has a temperature of 62° Fahr. Any slight deviation from this amount is termed the "index error," and is to be added to, or subtracted from, the reading, according as the graduation is greater or less than the true amount.

The capillarity and index corrections are to be made to the readings *first of all.*

In practice, the total error for scale and capillarity are usually ascertained by comparing each instrument, either directly or indirectly, with the standard barometer of some well-known public observatory (not with any instrument that may be called 'a standard'). In Bengal and Northern India generally, the barometer by Newman, No. 86, which is the standard of the Surveyor-General's Office in Calcutta, has for many years past been used as the general standard of reference, and the readings of all barometers are corrected to and made comparable therewith. This has been ascertained to read 0·011 inch higher than the Kew standard, and 0·013 higher than the Greenwich standard; therefore the correction of any instrument to the Calcutta standard is ·011 higher than to the Kew standard.[a]

The registers of a barometer, whose correction to some well-known public standard is unknown, are of very little use until that correction shall have been ascertained and applied. They may serve to shew the changes of pressure at the place itself; but these, taken by themselves, are of little value. In discussing any question of physical meteorology, we require to know the pressure at the place relatively to other places, and it is obvious that this comparison can be made only by reducing all to one common standard. The differences thus to be dealt with are very

[a] From the results of a comparison made by Captain Rikatcheff, I. R. N., and published in the Proceedings of the British Meteorological Society, vol. III, p. 248, I have deduced the following corrections of the standard barometers of some of the principal Observatories in Europe to the Kew barometer—

	Inch.		Inch.
Paris	—·006	Stockholm—	
Brussels	—·014	Royal Academy of Science	—·003
Utrecht	—·018	Upsala	+·004
Munich	—·010	Copenhagen—	
Berlin (Prof. Dove)	—·010	Academy of Agriculture	—·015
St. Petersburg—		Christiania	+·014
C.P. Observatory	+·008		
Pulkowa	+·017	Calcutta	—·011
Imperial Academy	—·004		

small in the tropics; and in comparison therewith, barometric errors are in general too large to be neglected.

13. Comparison of Barometers.—To ascertain the difference of two barometers, it is not enough to take one or two readings only. The number of readings required will depend on the care and accuracy with which they are taken; but they must be sufficiently numerous and varied in condition to eliminate those irregularities which arise from inequality of temperature in the parts of the instruments, inequality of action arising from friction, &c. A careful and skilful observer should take at least 20 readings of the two instruments simultaneously, half with a rising, and half with a falling, pressure; and either at such times as the temperature is steady, or at all events when it is changing but slowly; less skilled observers should take double or treble that number of readings, under the conditions specified. Every reading is then to be reduced for the temperature reading of the instrument itself (see next §); all readings should be rejected, the differences of which greatly exceed or fall short of the average of those taken under similar conditions, and the mean difference of the remaining readings will give the mean error.

During the comparison the barometers must be suspended with their cisterns at the same level, and care must be taken that they are vertical, and with the top of the column not above the observer's eye.

14. Correction for Temperature.—In reading a barometer, we measure the length of a column of mercury by means of a graduated scale usually made of brass. Both of these are subject to expansion and contraction, with every change of temperature. Were no correction made, the mercurial column, with every increase of temperature, would rise (or lengthen), and indicate an increased atmospheric pressure without any such change really having taken place. On the other hand, the brass rod, also expanding, would become longer than its graduation indicates, and therefore the mercurial column (as measured by it) would seem shorter than it really is. Thus, the two errors partly neutralize each other. But each inch of mercury expands 0·0001001 inch for every degree Fahr., while brass expands only 0·00001043 inch for each degree. Therefore, the expansion of the mercury is nearly ten times greater than that of the brass.

It has been said above that the brass scale is so graduated as to read standard inches at 62° Fahr. It is, however, at the temperature of 32° that barometric readings are supposed always to be made, and, therefore, it is to this latter temperature that all barometric readings are reduced.

This calculation is made by the formula[a]—

$$k = l\,\frac{0{\cdot}0001001(t-32) - 0{\cdot}00001043(t-62)}{1+0{\cdot}0001001(t-32)}$$

[a] Let h be the real height of the barometric column (reduced to 32°), l the reading of the scale, t the Fahrenheit temperature, β the co-efficient of volumetric expansion of the

when l is the observed reading of the barometer, t the observed temperature of the attached thermometer, and k the quantity to be deducted from l to reduce the latter to the freezing point value required.

Table I is thus calculated: the figures at the top of each column are different values of l: those at the side columns are the different values of t.

The method of using this table is fully explained in the remarks which preface the Tables.

15. Reduction to Sea Level.—Since the pressure of the air at any elevation depends chiefly on the mass of the atmosphere above its level, the higher the barometer is carried, the smaller the pressure it indicates, and its readings are frequently used to measure the height of mountains, &c.; *viz.*, by computing the height of the column of air, the weight of which is equal to that of the column of mercury, whose height is given by the difference of the barometric readings at the top of the mountain and at sea level. Conversely, if our object be to compare the pressures of the atmosphere in different parts of a country or of the globe, with a view to discovering those differences which are effective in producing winds, we must eliminate all differences due to the varying elevation of the places of observation. The most convenient mode of doing this is to reduce all to their equivalent values at sea level.[a]

Various formulæ and tables computed therefrom have been given for this purpose, and will be found in Boileau's tables, Guyot's tables, and many other publications. A very convenient table, sufficiently accurate for all ordinary purposes and very simple in use, has lately been computed and published by Captain Allan Cunningham at Roorkee. For heights below 500 feet, that given in the accompanying collection of tables (Table II) gives a sufficiently close result and is the simplest of all in application.

---

mercury, and a the co-efficient of linear expansion of the metal of the scale, for one degree Fahrenheit. Then, since the reading l of the scale is true at the temperature of 62° Fahr. at $t°$ it becomes $l\,[1 + (t-62)\,\alpha\,]$ and this is equal to the height of the mercurial column at the same temperature. Therefore we have—

$$h\,(1+ (t-32)\,\beta) = l\,(1+(t-62)\alpha)$$

$$h= l\,\frac{1+(t-62)\,\alpha}{1+(t-32)\,\beta}$$

and the correction $(l-h) = l\left(1-\frac{1+ (t-62)\,\alpha}{1+ (t-32)\,\beta}\right)$

$$= l\,\frac{(t-32)\beta-(t-62)\alpha}{1 + (t-32)\,\beta}$$

[a] There is a limit of elevation beyond which it is useless to reduce observations to sea level; because the reduction has no real physical meaning. Thus, at hill stations 6,000 or 7,000 feet above the plains, the pressure is that of a stratum of the atmosphere, in which the relations of pressure are, at certain times, demonstrably different from those on the plains below. The reduced pressures of these stations are, therefore, not comparable with those observed on the plains.

All these formulæ, however, assume certain conditions of temperature and vapour distribution, which, since these elements are subject to incessant disturbance, scarcely ever represent the actual state of the atmosphere at any given moment, though they may be approximately true on the mean of a large number of observations. The results, therefore, can be considered true for individual observations, only when the reduction is made for small heights, such as places on the lower part of the Gangetic plains; and the probable error increases with the elevation. This error is the more nearly eliminated, the larger the number of observations from which the mean result is obtained for the reduction.

16. **Determination of Level.**—A barometer, which at the sea level stands at 30 inches, falls, on an average, ·001 inch for every foot of elevation for the first 300 feet, when the air has a mean temperature of 90°; and by a greater amount for all lower temperatures. Since a barometer is read and corrected to the nearest thousandth of an inch, it is therefore necessary, in order to correct it truly for elevation, that the height of the mercury surface of the cistern above mean sea level should be ascertained (if possible, by spirit levelling), to the nearest foot. The elevation of the station, as given, for instance, on a map, is therefore insufficient for the purpose; and every pains must be taken to obtain the real level of the barometric cistern as accurately as possible. In most large stations of India, the elevations of certain bench marks have been fixed by spirit levelling; and, wherever such is the case, it is necessary only to run a line of levels from the bench mark to the barometer. It follows, of course, that if the barometer is moved to another place, the difference of level must be determined in the same manner, and, until this has been done and the resulting correction applied, the readings taken before and after the removal are not comparable with each other. *A very large proportion of the barometric registers hitherto kept in India are of little or no value, owing to the neglect of this precaution.* The effective differences of pressure in different parts of India are so small, that the reduced barometric values are rendered seriously misleading by errors of a few feet in the assigned elevation.

The elevation of stations to which no line of spirit levels has been carried, and which are not sufficiently near any Great Trigonometrical Survey station to allow of a line of levels being carried to it, may be obtained approximately by the barometric readings, *if all other corrections have been duly applied.* But for this purpose it is necessary, *first,* that the mean of several years' observations at the station are available for comparison; and, *second,* that the comparison can be made with series simultaneously recorded at, at least, three or four stations, lying in different directions around, and not at too great a distance; all these having equally been corrected to one and the same standard. Single observations,

and even short series, are quite insufficient for the purpose, especially if the elevation to be determined is considerable. Even with all precautions, such determinations can never have the trustworthiness of those obtained by the spirit level, for they proceed on the assumption that, in the long run, the pressure is the same at all the places *compared* when reduced to the same horizontal plane; and it is known that this is not the case in fact. There are, or may be, permanent differences of average pressure between different parts of the one and the same country. Barometric determinations of level are, therefore, to be resorted to only when more trustworthy methods are inapplicable.

17. Position of a Barometer.—A barometer, unlike a thermometer, *must be exposed as little as possible to changes of temperature.* The justness of the temperature correction depends upon all parts of the instrument having the same temperature as that shewn by its attached thermometer. But the mercurial column is inclosed in a glass tube, a bad conductor of heat, and this again usually in a metal tube, with an air space between. Consequently, the mercury is slow in acquiring or parting with heat; and it is only by keeping the temperature around as uniform as possible that the required conditions are even approximately fulfilled. *A barometer should, therefore, be kept in a well-enclosed room and the sun must never shine on it; nor must it be near a fire-place.*

The second point to be attended to is to obtain a good light, since the accuracy with which the instrument may be read much depends on the lighting. The source of light should be either on right or left hand; (not from the back, and still less from opposite the barometer). And a white surface, well illumined, should be provided behind the cistern, and also the upper part of the tube, to facilitate the accurate adjustment of the mercury level and the vernier.

If a barometer is provided with a back-board, a piece of white paper, about the size of a lady's visiting card, should be pasted behind that part of the tube at which the readings are taken, and another piece behind the cistern.

For barometers without back-boards, small card clips [Fig. 6] are now constructed at the Mathematical Instrument Manufactory in Calcutta, which can be attached to the instrument, with a clean white card C inserted. This is the best kind of reflector that can be employed. It is adjusted somewhat more obliquely than as shewn in the figure; so as to reflect the light from the right or left of the instrument.

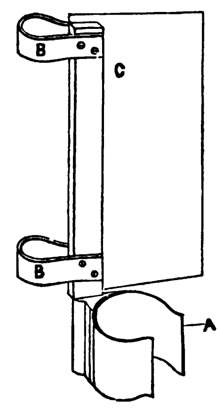

Figure 6. Card clip for barometer.

It has already been pointed out that *a barometer must be perfectly vertical,* and so hung that *the top of the column is not above the level of the observer's eye.* It may not be superfluous to add that *it must be kept clean,* and that the exposed part of the tube and cistern glass require occasional wiping (with a damp cloth if necessary).

A barometer should never be moved from the place it has habitually occupied, except such removal is absolutely unavoidable.

18. Tests of condition.—When a barometer is in good order, if slowly inclined till the mercury touches the top of the tube, it gives a sharp click at the moment of contact. If it fails to do this, there is air above the column. The surface of the mercury against the tube should be bright, and there should be no visible air specks. A dull surface shews that there is probably a film of air adhering to the glass. Air is, however, injurious only when it reaches the Torricellian vacuum above the column.

Sometimes little drops of mercury form by condensation on the inner surface of the tube in the Torricellian vacuum. They do not affect the reading and are of no importance.

If a barometer on the Fortin principle is found to have leaked a little at the cistern, it does not affect the reading, so long as sufficient mercury remains to admit of the mercury level being adjusted to the fiducial point. But if it continues to leak, it should be dismounted and put aside in an inverted position until it can be sent for repair; *but any leakage whatever in a barometer to which a capacity correction is applied, or one on the Kew principle, introduces a permanent error, which affects all its readings.*

19. Packing and carriage of barometers.—A barometer must always be packed and carried in an inverted position, that is, *cistern upwards,* (or else horizontal.) The safest mode of packing is to construct a dooly of bamboo of the form shewn in the annexed figure, [*Fig.* 7]; and to lash the barometer to it in the proper position and well surrounded by straw. The whole may then be covered with canvas or gunny cloth, leaving a hole for the insertion of a bamboo beneath the forks, by which it is to be carried by two coolies in the manner of an ordinary dooly. Such a package may be sent safely by rail or ship, provided ordinary care be used in placing and moving it. If a barometer is on Fortin's principle, before packing it, the cistern screw should be

Figure 7. Dooly for carrying barometers.

turned till a small air space only, (about as large as the bowl of a tea spoon,) is left in the cistern.

20. Selection of a barometer.—In the hands of a practised observer, a barometer on Fortin's principle is the most convenient. The best yet tried in the observatories of the Meteorological Department are the Newman's large standards, and the small standards constructed by Casella, which latter have a leather bag at the bottom of the cistern. Some makers have, of late years, substituted for this bag, a solid glass piston working through a leather collar; these have been largely tried, but they are so subject to leakage as to be quite unfit for the dry climate of the interior of India.

The chief objection to Fortin's barometer is the liability of the mercury to oxidise; but, when the mercury is carefully purified, it may be kept in good condition for many years. The cistern is easily opened and the mercury removed and cleaned by any person accustomed to the manipulation of such instruments; but it should not be attempted by the unskilled.

The oxide is removed by passing the mercury through a filter made of a cone of writing paper with a pin hole at the apex. The cistern must be wiped out with a clean cloth before the mercury is returned. If, however, the mercury contains foreign metals dissolved in it, it must be purified by chemical means or must be re-distilled.

Newman's standards are also excellent barometers. There are many of them in use in India, and with proper care they stand well in all climates; but they are costly, and heavy in transport.

For stations at which the observers are less skilled, small standards on the Kew principle are best fitted. Marine barometers on the same principle may also be employed, but many of them are slow in action, and they fail to shew the full daily range of pressure.

Barometers with wooden cases, such as those used in most ships, and such as are set up in the halls of private dwellings, are not fitted for the purposes of scientific observation, and the words "change," "fair," "set fair," &c., frequently marked on them are meaningless and misleading in India. The remarks engraved on Fitzroy's barometers are scarcely more applicable in Bengal.

21. Aneroids.—For meteorological purposes, aneroids cannot be trusted in India, unless they can be compared frequently with a mercurial barometer as a standard of reference. The delicacy of their machinery renders them very liable to derangement in transport, and there is much difficulty in ascertaining their temperature correction. They are useful for rough hypsometrical observations, and that is their chief use.

THERMOMETER.

22. Principle and construction.—A thermometer is an instrument for measuring the temperature or warmth of the air or other medium, by means of the expansion of a fluid enclosed in a glass bulb. Nearly all fluids expand and occupy a greater space when warmed, but that used for thermometers is usually either mercury or spirit of wine. It quite fills the bulb and extends some distance up a fine tube opening into it; and, as the bore of the tube is very small, a very small change in the volume or bulk of the fluid is made perceptible by its extension or regression in the tube.

23. Principle of graduation.—There are two fixed points of temperature obtainable without much difficulty, and with great accuracy; *viz.*, that at which ice melts, and that of the steam given off by boiling water at London, when the barometer reduced to the freezing point stands at 29·905 inches.[a] The difference of these temperatures on the thermometers in general use in England, India and most English-speaking countries, is divided into 180 parts, termed degrees; and the lower temperature being called 32°, the higher becomes $32° + 180° = 212°$.

24. Meaning of degrees of temperature.—In graduating standard thermometers, the tubes, when filled, are immersed first in melting ice, and then in the steam of boiling water, and marks are made on the tube to indicate the points at which the fluid stands in the two trials respectively. The interval is then divided into 180 parts. A number of similar, equal divisions are afterwards set off below the freezing point, and the 32nd is termed 0°. Thus, it will be understood that degrees are purely conventional divisions; and not only *might* the interval between the melting point of ice (commonly termed the freezing point) and the temperature of steam (as above defined) be sub-divided into any other number of parts than 180, but two such other systems of sub-division are very widely employed. That just described is termed the Fahrenheit scale, and is generally used in England and America; another, used almost exclusively in France, and by chemists and physicists of all countries, and termed the Celsius or centigrade scale, has 100 degrees between the freezing and boiling points[b]; and the former is termed 0°, the latter 100°; and in Germany and Russia the same interval is generally divided into

[a] This pressure would be equal to 29·924 ins. at Calcutta.

[b] The boiling point of the centigrade scale, though very nearly, is not accurately the same as that of the Fahrenheit scale.—See Balfour Stewart's *Elementary Treatise on Heat*, p. 129.

80 parts, the freezing point being 0°, and the boiling point 80°. This is termed Reaumur's scale.

25. Scales.—The tube, bulb, and scale are the essentials of every thermometer; but the scale is often engraved on the tube, and sometimes no other scale is attached; thermometers used by meteorologists, except radiation thermometers [§ 45], generally have, however, an attached scale as well, which is especially made to correspond to the graduation on the tube. Consequently, a scale is of use only for that particular tube for which it has been engraved.

26. Errors and corrections of thermometers.—Although there has been a great improvement in the manufacture of thermometers of late years, still very few instruments are free from error, and none can be *assumed* to be accurate. The causes of error are various. In the first place, the bore of the thermometer may be not quite equal throughout, in which case equal divisions on the scale will not correspond to equal increments of expansion of the fluid; or the graduation itself may not have been quite accurate; and, secondly, as the glass of the bulb undergoes a slow contraction for some years after the instrument has been made[a], it is generally found that, after a lapse of time, the thermometer gives too high a reading in all parts of the scale. Errors, thus arising, not infrequently amount to a degree, or even more, especially in the case of spirit thermometers, the ratio of expansion of which fluid does not accord with that of mercury; and, consequently, every instrument should be tested and its errors determined at different parts of the scale, and the corresponding corrections should be applied to all its readings.

27. Comparison of thermometers.—It would be too tedious to eliminate the errors of thermometers for ordinary observation by absolute methods. It is sufficient if the freezing point be verified by immersing the thermometer in crushed melting ice, and if a comparison be made with a good standard thermometer, (the errors of which are known) at four or five higher temperatures, such as divide and comprehend the range through which it is intended to register. But to do even this much satisfactorily requires some practice and certain proper appliances; and it should always be performed at a depôt or central observatory before the instrument is issued. A comparison may, however, be made, without much difficulty, at and near the temperature of the place, by removing the attached scales of the thermometers to be compared, and immersing the tubes in water in the positions with which they are ordinarily

---

[a] A thermometer, in the possession of Prof. Joule of Manchester, was found by him to be still undergoing a progressive rise of the freezing point, after 29 years from the time of its construction. The total rise in this time was a fraction less than 1 degree Fahrenheit, more than half of which took place in the first four years.—See *Proceedings of the Literary and Philosophical Society of Manchester*, vol. XII, page 73.

read ; *i. e.*, if, like most self-registering thermometers, their suspension is horizontal, they must be immersed horizontally in the water and so read. This is chiefly important with mercurial thermometers. If this be impracticable, the thermometer may be tested in the vertical position, and afterwards, when it has acquired the temperature of the air, or is immersed in a broad vessel of water of uniform temperature, it may be read in both positions and the difference added to the error. The comparison may be extended in this manner to a moderate distance, (10° or 15°) above and below the actual temperature; the water being stirred meanwhile to ensure a uniform temperature. But the greater the difference, the more difficult is it, by such means, to ensure uniformity of temperature, and therefore, a trustworthy result, if one instrument is much slower than the other in undergoing changes of temperature.

A comparison of thermometers suspended, side by side, in the air, when the temperature is subject to rapid changes, is of little or no use, unless protracted over a long period, during which a great number of readings are recorded with a rising, and an equal number with a falling temperature. Even then a mean error only is obtained, whereas the comparison in water gives the variation of the error at different parts of the scale.

The standard should be either one graduated, calibrated and otherwise verified at the Kew observatory, or a thermometer that has been thoroughly compared with such a Kew standard.

The errors of thermometers, however small, cannot be considered as trivial and negligible. Even though it may be the observer's practice to neglect all fractional parts of a degree in reading his thermometers, an error of only 0·1° will still appear in the mean of a large number of such readings, on comparing it with the mean reading of a standard recorded simultaneously; and in many investigations, such as, *e. g.*, the effect of lunar heat, and, even in comparing the mean temperatures of successive years, an error of one or two tenths of a degree appreciably affects the result.

28. Precautions in reading thermometers.—To read a thermometer accurately requires some little care.

1st.—The eye must be exactly at the level of the reading, if the thermometer is vertical; and, in all cases, must be so situated, that a line drawn from the eye to the top of the column would cut the axis exactly at right angles. The reason for this precaution is the same as that already given in the case of the barometer. If the eye is above the reading, however little, the reading will be too high; and *vice versâ*. This is a point frequently neglected by careless observers.

2nd.—The thermometer must be read quickly, and the face and head must not be very near it; otherwise, it will be affected by the warmth radiated from the body.

3rd.—It must be read to the nearest tenth of a degree by estimation. There is no difficulty in this, and to neglect it is a mark of a careless observer.

4th.—Spirit thermometers are read to the lowest part of the concave surface of the column, mercurial thermometers to the top of the convexity.

29. Varieties of thermometers.—Several variations are made in thermometers intended for special purposes. The principal of these requiring notice are—

The standard (dry bulb)	...	For taking the temperature of air at the moment of observation.
Maximum thermometer	...	For registering the highest temperature attained in the day or other period.
Minimum "	...	For registering the lowest temperature attained.
Solar radiation thermometer	...	For measuring the highest temperature of equilibrium in the sun's rays, when the surrounding objects are constant.
Grass " "	...	For measuring the cooling of air in contact with the earth's surface at night.

30. The standard thermometer (dry bulb).—This is the simplest form of the instrument, and requires no description beyond what has already been given. It is graduated with care, and, when the other thermometers have not been separately verified, serves as the standard with which these others are compared. But a matter which requires great consideration is, 'how to place the instrument so that it may shew truly all changes in the temperature of the air.' And this requires that a few words be said about the mode in which heat acts on the thermometer. These remarks apply equally to the ordinary maximum and minimum thermometers, and to the hygrometers presently to be described.

31. Precautions in placing thermometers.—A thermometer suspended in the air is affected by heat, which reaches it in two different ways; *firstly*, by the contact of the air actually around and bathing the bulb, and the temperature of which is to be measured; and, *secondly*, by heat which is given off from all solid and other objects around, at all times, in all directions, which travels through air and space with the same velocity as light, and, like light, passes freely through some bodies, is absorbed by others, and is reflected by polished metallic surfaces. This last is termed *radiant heat* or, more properly, simply *radiation*. Now, when the object is to ascertain the temperature of the air, the influence

of changes in radiation must be got rid of as much as possible. But it is impossible so to place a thermometer that it is uninfluenced by radiation; for, if even it be screened from the heat radiating from surrounding objects, (which may be effected to a great extent,) it will then radiate off its own heat faster than it can be warmed by the air; and will equally fail, therefore, to show what is required, *viz.*, the temperature of the air.

32. Joule's apparatus.—The alternative, then, is to place the thermometer in such a position that the effects of radiation and air-temperature combined may be as nearly as possible identical with those of the latter alone. An arrangement which attains this object accurately has been contrived by Mr. Joule. It consists of a cylindrical copper vessel surrounding a wide tube of the same metal, which is open at both ends. In the axis of the tube is suspended, by a filament of unspun silk, a very light spiral of metallic wire, which carries a small light mirror above the orifice of the tube. The least current of air passing up or down the tube turns the spiral, and the motion is indicated by a ray of light reflected from the mirror. If there be the smallest difference of temperature between the tube and the air around, such currents will be set in motion, so that, when the spiral is motionless in the open tube, this is an indication that there is no such difference of temperature. The temperature of the tube is regulated by filling the cylindrical vessel with water, immersed in which, an accurate thermometer shews the degree of its temperature.

33. Sling thermometers.—An admirable and simple contrivance for obtaining the actual temperature of the air at the time of observation, is that known as the *thermomètre à fronde* or sling thermometer. This is a small thermometer without any attached scale, which is either fixed on a revolving frame, or terminates at its upper end in a glass ring, to which is attached a piece of strong twine about eighteen inches or two feet long. The free end of the string is coiled once or twice round the finger to prevent its slipping, and the thermometer is then swung round five or six times in the air and rapidly read off. The effect of this proceeding is to renew the air around the bulb so rapidly, that any excess of heat received by radiation is lost to the air, and *vice versâ*. It is found that, even in the sunshine, the real temperature of the air may be obtained approximately by the use of this instrument. The temperature of the wet bulb thermometer may be obtained by the same method, but the thermometer should then be swung slowly.

34. Thermometer sheds.—Such an apparatus as Joule's would afford a valuable test of the efficacy of different kinds of exposure, but it is far too delicate for ordinary use. Meanwhile, it has been sought to attain the object in view by shading the thermometer from the sun and sky,

and also from the ground or walls, heated by the sun or cooled by free radiation: exposing it at the same time to the freest circulation of the air. With this view the shed and cage represented in Plate I have been generally adopted in India. The shed consists of a frame-work eighteen or twenty feet long and fourteen or sixteen feet wide, well thatched above and open all round. It should be erected in an open grassy place, at a distance of not less than fifty feet from any wall or other radiating surface, the ridge pole pointing north and south. It has an opening above to allow of the escape of heated air. This opening, however, should be small, and may be advantageously replaced by a section of a large bamboo, to serve as a ventilating pipe, inserted through the thatch immediately beyond the ridge pole. The cage containing the thermometers is affixed to the southern pole and faces to the north. The eaves should be between five feet and five feet six inches above the ground.

35. Objections to verandahs and stands.—Other modes of exposing thermometers are,—suspending them in the verandah of a house, or on an open stand, such as that designed by Mr. Glaisher, or that figured by Colonel James in his well-known "Instructions." Both of these are open to serious objection. The walls of a house absorb a large quantity of heat during the day time and give it out again during the night, while the circulation of air in a verandah is necessarily less free than in an open shed. The result is, that a thermometer thus exposed, shews a temperature too low in the day-time and too high at night. In 1866 and 1867, Dr. J. C. Bow, at Chunar, instituted a comparison between the temperatures shewn by thermometers exposed in a verandah and under a thatched shed; and found that, while in the former position the mean daily range was 12° only, in the latter it was 24° in 1866; and in 1867, 11° in the former and 23° in the latter. Thus, half or more than half of the daily range was lost in the verandah by the want of free exposure. The means for the month and the year were nearly the same in the two cases; but while, on an average, the day temperature was 6° too low, that of the night was by the same amount too high.

On the other hand, the open stand fails to afford sufficient protection against radiation, and in most parts of India the effect of this must be very great. No comparative observations have hitherto been made in India to test its intensity, but it must certainly be far greater than in an English climate; and Mr. Plummer found that, at Durham, the observations of thermometers on a Glaisher stand, shewed a diurnal range of temperature from 2·0° to 8·0° greater than others exposed in a pent-house not very dissimilar from the sheds used in India. Moreover, the Glaisher stand gave a mean temperature 1·3° too high in August, and 0·4° too low in December. There was indeed a difference in the elevation of the thermometers which prevents the comparison being quite satisfactory;

but there can be little doubt that much of the discrepancy observed was attributable to radiation.

36. Maximum thermometer in air.—The object of maximum thermometers is to register the highest temperature attained by the air during the day. This is effected by various contrivances. But it will be sufficient to describe those most in use.

37. Rutherford's maximum.—In Rutherford's (now not much used) the mercury, in expanding up the tube, pushes before it a small porcelain index, which it leaves at the highest point, when the column has reached its limit and contracts on cooling. The lower end of this index, or that touching the mercury, shows the reading. Above it is a small steel pin which, like the porcelain index, moves freely in the tube.

The thermometer is to be re-set after an observation has been recorded. This may generally be effected by simply placing the instrument upright (bulb downwards), when the index will drop to the mercurial column. If it does not, it may be dragged down by applying a small magnet to the steel pin above it and pulling the latter down by the attraction of the magnet. A magnet is furnished with the instrument for this purpose. The thermometer is then replaced in the horizontal position.

38. Negretti and Zambra's maximum.—This instrument differs from the above in having no separate index, so that the column marks its own maximum. The tube is bent, more or less, just above the bulb; and a slight constriction at the bend causes the mercury column to break at this point, when the fluid begins to contract. The column, therefore, remains at the highest point.

This thermometer is set by merely detaching the suspension ring at the bulb end, and lowering that end of the instrument towards the vertical, or, if more be necessary, by removing it and gently jerking the lower end of the mounting on the palm of the hand.

39. Phillip's maximum.—This thermometer is constructed with a small bubble of air introduced into the column at about 1½ inches from the end. When the mercury contracts after reaching its highest point, all that portion beyond the air bubble remains, marking the highest temperature reached. In the use of this thermometer, it is necessary that the direction in §42 should be strictly observed. If the stem is horizontal, the elasticity of the air bubble will sometimes drive forward the column above it half a degree or more, and derange the reading by that amount.

This instrument also is set by detaching the suspension at the bulb end, and gently lowering the instrument towards the vertical.

40. Minimum thermometer in air.—The object of this thermometer is to register the lowest temperature to which the air has cooled during the night. It will suffice to describe that form of the instrument in which the fluid is spirit, and which is in universal use in India.

41. Rutherford's minimum.—This is a spirit thermometer, with a horizontal column, and has a small black glass rod (of the form of a pin with a head at each end) immersed in the column. The spirit adheres to this, so that, if even the thermometer be inverted, it will not leave the spirit. Consequently, when the fluid contracts, the glass pin is drawn back to the lowest point reached; but when the spirit expands with an increase of temperature, the index remains at its lowest position, and the spirit passes freely by it. The *upper end of the index* (that furthest from the bulb) indicates the minimum temperature. Before the reading of a spirit thermometer is recorded, the upper part of the tube, *and particularly that part covered by the brass staple* which fixes it to the scale, should *invariably* be examined, to ensure that the column is entire and that no drop of spirit has become detached and lodged in the upper part of the tube. If such is the case, the reading must be rejected as untrustworthy, since it is uncertain whether the separation took place before or after the index reached its position.

To re-set the thermometer after an observation, hold it in a vertical position, bulb upwards, and the index will fall slowly till it reaches the upper end of the column.

42. Suspension.—The above thermometers are to be suspended with the column nearly horizontal, (the bulb end about half an inch lower than the upper end of the scale).

43. Restoration of a broken column.—Spirit thermometers are very liable to derangement in travelling, by the separation of the spirit column; which, instead of being continuous, becomes distributed in two or three divisions through the upper part of the bore. Sometimes the index is shaken out of the spirit and is found fixed at the upper end of the bore. And, when the instrument is in use and not subject to concussion, it frequently happens that the vapour which fills the upper part of the tube is condensed in a drop in its upper part (not seldom beneath the brass staple that fixes the tube). In order to rectify the column, proceed in the following manner:—

(1.) If the thermometer be provided with a stout attached scale of wood, porcelain, &c., grasp it in the right hand by the upper end, holding the bulb end downwards (and taking care not to press on the tube, which might risk breaking it). Stretch out the arm above the head, keeping the bulb at a distance, and swing the instrument down rapidly towards the feet. This movement, repeated a few times, will generally restore the column.

(2.) In the case of a grass radiation thermometer [§ 50] which has no attached scale, the above proceeding is dangerous, as the thermometer is likely to be flung out of the protecting tube and broken. The following plan is better. Grasp the instrument between the bulb and the protecting tube with the tips of the thumb and the fore and middle fingers of the right hand, and grip the tube in the fork of the two fingers. Then, holding the left hand, palm upwards, hit it smartly with the base of the right hand, repeating the blow until the index is dislodged, and the column restored. The mode of holding the thermometer is shown in the accompanying figure [Figure 8].

Figure 8. Method of holding thermometer to restore column.

44. Sykes' thermometer.—This instrument registers both the maximum and minimum temperatures in a single tube. The tube is bent in the shape of an U, with the limbs vertical, and each limb bears a scale. One of the limbs, (we will assume the right,) terminates above in a bulb filled with spirit, while the bend of the tube and both limbs up to a certain height are filled with mercury. A little spirit is introduced into the other (or left-hand) limb above the mercury, but the bulb in which this limb terminates contains only vapour. Immersed in the spirit column in each limb is a small index, a steel pin with a light spring attached, which prevents its moving in the tube by mere gravitation. By means of a small magnet, it may, however, be moved up and down; and, in setting the instrument, both indices are made to rest on the top of the two mercurial columns. When the temperature rises, the spirit filling the right-hand bulb expands and pushes the mercury column before it, causing it to rise in the opposite limb. The minimum index remains in its original position, but the maximum index in the left-hand limb is pushed before the advancing mercurial column, and on the retreat of the latter is left, marking the highest temperature reached. With a falling temperature, the spirit contracts in the right-hand limb,

followed by the mercurial column, which then drives the minimum index before it and leaves it marking the lowest temperature.

45. Radiation thermometers.—These thermometers, being intended to register the gain or loss of heat by radiation, must be freely exposed to the sky without cover of any kind. They are of two kinds, *viz.*, a self-registering maximum thermometer for obtaining the temperature acquired when exposed, under constant conditions, to the sun's radiation; and a self-registering minimum for ascertaining the loss of heat by radiation to the sky during the night.

46. Solar radiation thermometer.—The use of this instrument is to give a relative measure of the intensity of the sun's heat. It consists of a mercurial maximum thermometer, (the bulb of which, together with a portion of the stem, is coated with lamp-black,) enclosed in a larger tube, from which the air has been exhausted before being sealed.

The lamp-black absorbs the radiation from the sun, as well as that which it receives from all objects around, and thus the bulb of the thermometer becomes heated. At the same time it is giving out its own heat to surrounding objects; and the temperature shown by the thermometer becomes constant, when the heat given out in each second of time is exactly equal to that which it receives. Any change made in the surroundings, for instance, the substitution of grass for bare earth beneath the instrument, of a white-washed wall for a naked brick-wall in the neighbourhood, or a wall for a bush, alters the conditions of equilibrium. Consequently, in order that the readings at one time may be strictly comparable with those at another time—in other words, in order that the instrument may show the variations of the sun's radiation and no other,—the surrounding conditions must always be the same. This means that the thermometer must always be exposed in the same place, with the same objects around, and at the same height above the ground. At Allahabad there was a difference of 6° between the readings of two thermometers otherwise reading alike, when one was placed over thickly-growing grass, the other where the grass was somewhat thin, on one and the same lawn.

The outside of the enclosing tube being exposed to the air, the temperature of the tube is lowered by its contact, and, as this tube surrounds the thermometer, the temperature of the latter is affected in its turn. When the sun is shining, the air close to the ground is hotter than that at a greater height above it. Hence, a further reason that the thermometer must always be at the same height above the ground. The effect of the sun's radiation is indicated by the *difference* of the temperature shown by the solar thermometer and that of the air.[a]

---

[a] In practice this is the difference between the maximum of the radiation thermometer and the maximum shade temperature.

Owing to circumstances not yet fully explained, there is frequently a great difference in the readings of solar thermometers of the same pattern, amounting to two or three degrees, and sometimes very much more. It cannot, therefore, be assumed that the readings of two thermometers are even approximately comparable with each other, unless they have previously been compared by exposure to the sun, side by side, under precisely the same circumstances.

The vacuum in these thermometers is frequently far from perfect, and is variable. The more air there is in the tube, the more does it cool the thermometer by convection. If, therefore, the outer tube be cracked, however slightly, air penetrates and the thermometer must be rejected as unserviceable.

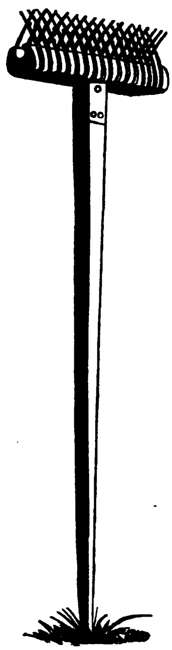

Figure 9. Sun thermometer stand.

47. Stand for sun thermometer.—Until lately it was the practice at most stations in Bengal to expose the sun thermometer on two forked sticks, one foot above the ground. In this position, however, its indications are so greatly influenced by the condition of the small patch of ground immediately beneath the instrument, that it has been found better to expose it on a stand four feet high, which somewhat diminishes the merely local effect. This plan has been recommended as the result of some experiments made by Mr. Stow in England. The stand adopted by the Meteorological Department is represented in Figure 9. It differs from that recommended by Mr. Stow chiefly in being provided with a cage of sharpened wires, which are very necessary in India to prevent crows and other mischievously disposed birds resorting to the stand as a perch.

This stand is introduced only at newly-established stations, and at others where, owing either to the destruction of the thermometer, the removal of the observatory or other cause, the strict uniformity of the observations has been interrupted. Otherwise, it is of more importance to obtain observations strictly comparable with those of former years than to introduce an improvement in the exposure.

48. Time of exposure.—On a clear day, the sun's greatest heat is at noon, and the highest temperature recorded by the sun thermometer occurs shortly afterwards; since, for a short time, the increase in the temperature of the air and of radiating objects around, more than counteracts the decrease of direct solar radiation. But the sun thermometer should be exposed at least from 10 A. M., to 4 P. M., since, if

clouds are about, the highest radiation temperature may be either earlier or later than noon. It should always be removed during the night, *and carefully wiped clean* before it is replaced on the stand next day.

In the earlier months of the year (February to April) in which hail sometimes falls, the thermometer should be read and removed when a storm is imminent.

49. Comparison of sun thermometers.—These thermometers cannot be sufficiently compared in the ordinary way, since their irregularities are affected by variations in the vacuum of the tube, the extent of the lamp-black coating, and probably other causes not inherent to the graduation; a rigorous verification of the thermometer in respect of contact temperatures would, therefore, be of little use. The method now adopted is to select one instrument as an arbitrary standard, and to reduce the readings of all others to the same value, after comparing them by free exposure to the sun, side by side, under identical conditions, till thirty or forty readings have been recorded. Comparison in the shade is no criterion of their difference in the sun. Two thermometers which agree well in the shade may differ by 3° or 4° in the sun.

50. Grass radiation thermometer.—At night the earth and all objects on its surface give out by radiation towards the sky the heat they have received during the day; and if the sky be clear and free from clouds, receive but little in return. Being at first warmer than the air, they continue to cool down below the temperature of the air, and eventually cool the air itself in contact with them. If any screen, natural or artificial, be interposed between any object (thus cooling) and the sky, the radiation is arrested, and in part reflected. A cloud, a tree or an umbrella thus checks radiation at once.

The object of the grass radiation thermometer is to ascertain the extent to which such cooling proceeds, and it follows from what has been said that it must be freely exposed, away from trees or buildings. It has been usual to place it on grass or other closely-growing vegetation, but above it and quite unscreened by it. It consists of a minimum thermometer without any attached scale, the tube being graduated. To give the instrument greater strength, the stem is generally enclosed in a stout glass tube [Fig. 8]. It is set in the same way as an ordinary minimum; and must be placed horizontally on the grass or, failing this, on a surface of wool, such as a piece of country blanket [§ 51].

The enclosing tube is rarely air-tight, and damp air sometimes enters and deposits dew on the inside, which, if allowed to accumulate, much obscures the readings. In such case the thermometer should be taken out, the tube wiped out dry, and the thermometer replaced. This should be repeated as often as necessary. If the graduation becomes obliterated, it may be easily rendered distinct by the proceeding described in § 52.

51. Exposure and protection.—In countries, such as some parts of the Punjáb, Rájpútána, and the Dekhan, where, during the hot weather, grass will not grow, and where the ground is bare or nearly so, perhaps for miles around, no attempt should be made to produce an artificial grass surface by watering. The evaporation from the watered surface will affect the temperature quite as much probably as radiation. In such cases it should be laid on a piece of dark coloured country blanket of three or four-fold thickness, nailed on a board, and laid on the ground.

Radiation thermometers are more liable to destruction by birds and animals than other kinds of thermometers, but *no screen of any kind must under any circumstances be placed over their bulbs.* With a little care and attention they may be preserved for a long time uninjured. The place where they are exposed should be surrounded by a strong fence, and, if birds are very troublesome, a stick, with a few strips of rag attached, or a light whirligig a short distance from the instrument, will generally suffice to scare them.

The grass radiation thermometer should be removed during the day to a secure place.

52. Restoration of obliterated graduation on tube.—The black pigment with which the graduation on thermometer tubes is rendered distinct, is sometimes washed out, and the graduation becomes difficult to read. It may be restored by rubbing a little common lampblack powder along the tube with the finger, the powder being used either dry, or better, slightly moistened. A trial or two will show the pressure to be used in rubbing the powder into the engraved marks and afterwards wiping off the excess; which may be done by pressing lightly, without removing that in the incisions on the stem.

ACTINOMETER.

53. Object and principle.—A sun thermometer shows the temperature attained by exposure to the rays of the sun, under certain definite conditions, but it does not show the *quantity of heat* received from the sun. For this purpose we must resort to the actinometer.

The actinometer is an instrument for measuring the quantity of radiation received from the sun in a certain fixed time, say a minute. It consists essentially of a thermometer having a very large bulb, so constructed that it will absorb the whole, or nearly the whole, of the sun's radiation. When exposed to the full sunshine, it absorbs the radiation, but at the same time it is radiating away its own absorbed heat; and this the faster, the higher its temperature. The whole quantity, therefore, received from the sun in the minute, is that which is measured by the expansion of the fluid, *plus* that which it radiates away in the same time. This latter quantity is ascertained by observing the expansion of the fluid in the sun and its contraction in the shade, alternately, in successive minutes. The contraction in the shade is the measure of the heat lost in the minute, the expansion in the sun is the measure of that which is absorbed *in excess* of that which is lost. The sum of the two is the whole quantity absorbed in the minute. The quantity of heat thus measured is that which falls in a minute, on a surface equal to that of the solar shadow cast by the actinometer bulb on a flat surface at right angles to the path of the incident ray. This heat is absorbed by a constant quantity of fluid. If then we know the quantity (*i. e.*, the mass) of the fluid, its specific heat, and its rise of temperature, the product of these, divided by the surface and the time, will give the number of units of heat[a], falling in the unit of time on an unit of surface.

54. Actinometers.—A description of Herschel's actinometer will be found in the Admiralty Manual of Scientific Enquiry (Art. Meteorology), that of Pouillet's Pyrheliometer in Taylor's Scientific Memoirs, volume IV, page 45, and also in Tyndall's Heat a Mode of Motion, and Balfour Stewart's Treatise on Heat, &c. As the instrument best adapted to Indian requirements, being cheap, simple and portable, and little liable to derangement, Hodgkinson's actinometer is that which I shall select for description here, merely premising that the principle is the same in all.

[a] The unit of heat in English measures is the quantity of heat that will raise 1lb avoirdupois of water from 0° to 1° Fahrenheit. For the further explanation of this and other terms here employed, see Part II.

55. Hodgkinson's actinometer.—A full description of this instrument and the method of using it will be found in the Proceedings of the Royal Society, volume XV, page 321, and also in the Philosophical Magazine, 1867, volume XXXIII, page 304. In form it bears much resemblance to a thermometer, with a spherical bulb about one inch in diameter. The stem has a very fine bore up to within two inches of the top of the scale, where it expands into a wide tube 1½ inch long, and terminates above in an ellipsoidal bulb, somewhat wider than the tube. It is attached to an ivory scale, the lower end of which is 1½ inch above the spherical bulb. The scale of the narrow bore is graduated in millimetres, and it is the expansion and contraction in this portion of the stem that is the subject of observation. The scale of the wide tube at top is graduated as a thermometer, having a centigrade division on one side, a Fahrenheit division on the other. In two instruments before me, the zero of the millimetre graduation corresponds to 40° Fahr. of the thermometer scale; and in one 255mm., in the other 269mm. correspond to a range of 5°. The fluid is alcohol, coloured deep blue (opaque, except in a thin film,) with aniline blue or litmus.

When in use, the spherical bulb is inserted through a lateral opening, and adjusted in the axis of a brass tube 2½ inches wide and 22 inches long, blackened inside, and having at each end a glass cover and an outer brass cap; both of which are removable at pleasure. The stem of the actinometer above the bulb is clasped by a split cork, which closes the lateral opening in the brass tube. This tube is movable about a horizontal axis fitted with a brass pin; which, together, allow of a free movement in altitude and azimuth. The pin works in a socket, which, when the instrument is in use, may be screwed into the top of a staff of convenient height, which, being driven into the ground, serves as a support.

56. Use of the actinometer.—Thus arranged, the tube is pointed to the sun; and, the brass caps being removed, it is adjusted in this position, by the foreshortening of the shadow, or by the shadow of the bulb and tube thrown on any light-coloured surface at the lower end of the tube. The instrument may be used either with or without the glass cap. But, as this cap stops a considerable portion of the sun's heat, the difference of the readings with and without the cap must be ascertained by repeated comparison under both conditions, with a second instrument exposed at the same time without its glass. Comparing the two sets of results, a factor is obtained, which, multiplied into the "glass-on" observations, gives their equivalent value in "glass-off" observations. A factor must thus be found for each individual glass used, and each glass must be marked to facilitate identification.

The first step is to expose the actinometer until it has acquired a convenient working temperature. What this is, can be ascertained only

by experience. It is determined by the condition that the expansion of the column during the minute of exposure to the sun should be about equal to its fall during the minute of shaded exposure. But Mr. Henessey's experience in India[a] is to the effect that it is impossible to continue a series of observations for any lengthened period (as, say, two hours) without introducing breaks of several minutes in its continuity, since "this adjustment becomes changed by any considerable alteration in the radiation."

Supposing that a proper working temperature has been found, this temperature is noted, and then all the fluid in the wide part of the column is thrown off into the upper ellipsoidal bulb. In the intruments before me, the top of the narrow column corresponds in one case to the scale temperature of 45·6° in the other to that of 45·4°. If then t be the temperature read before throwing off the upper part of the column, t – 45·6° in the one case and t – 45·4° in the other, must be added to the apparent temperature of the subsequent readings, to give the real temperature. It is required to know this, because the ratio of expansion of the fluid (alcohol) is different at different temperatures.

There should be two observers, one to give the time from a chronometer, or watch showing seconds, and to record the readings; the other to read and work the actinometer. To begin with, having brought the instrument to a convenient working temperature and thrown off, and having allowed the residual column to contract through about one-half of the scale, turn the tube to an unclouded part of the sky, and at the even quarter minute, uncap it, taking the reading at the same instant. This must be done quickly, as the column is in motion, and its position must be read by estimation to the tenth of a millimetre. After a minute's exposure, the observer with the chronometer calls "time." At the same instant the actinometer column is read off. The tube is then turned to the sun. Being duly adjusted by means of its shadow, the observer waits till a quarter of a minute has elapsed, "time" is then called, the instrument read off quickly, and the sun exposure continues for one minute, when "time" is again called, the actinometer again read off and turned away for the shade observation. A complete observation consists of two shade observations and the intervening 'sun.' But in practice it is found better to combine these, in groups of 3, 4 or 5 'sun' observations, and of the initial final and intervening 'shade' observations, and to take the mean of each. As already explained, the mean fall in the shade added to the mean rise in the sun, is the measure of the mean quantity of heat absorbed.

57. Reduction.—But in what terms? It is, of course, desirable, that the observations should be reduced to units of heat per unit of time (the

[a] Proceedings of the Royal Society, volume XIX, p. 225.

second), per unit of surface (the square foot). This, however, is not at present practicable, since prolonged and elaborate experiments are required to obtain the constants of such a reduction. For the present we must content ourselves with a reduction to the indications of a standard instrument, (that at Kew observatory) merely correcting the observations for "glass-on" temperature, and index difference. The method of obtaining the first has been already noticed: the reduction for temperature has been usually made by Kopp's table of the expansion of alcohol at different temperatures, given in Gmelin's Chemistry. This temperature correction is applied first of all, and afterwards that for "glass-on," lastly the index correction is to be applied; to obtain which, the instrument used must have been compared either directly or indirectly with the Kew standard.

The altitude of the sun may be observed at the time of the observation, or may be afterwards found by calculation, the time and latitude being known.

HYGROMETER.

58. Object of the observations.—Every one is familiar with the fact that, in some states of the atmosphere, a piece of wet cloth, hung up in a shady place, will dry quickly; and that sometimes, as in the Upper Provinces in April and May, the air is so dry that the covers of books and nibs of quill pens curl up, furniture cracks and opens at the joints, &c., owing to the evaporation of the small quantity of moisture that these articles usually hold absorbed. On the other hand, during the rains in Eastern Bengal, on the west coasts of India and Burma, &c., it is almost impossible to keep books, clothes, &c., from becoming damp and mouldy. These differences depend on what is termed the humidity of the air, that is to say, on the quantity of vapour it contains. In the former condition the air is said to be dry, in the latter very moist. The object of the hygrometer is to ascertain the quantity of vapour actually present in it.

59. Absolute and relative humidity, saturation and dew point.—The quantity of vapour which can exist in a given space depends on the temperature, and is appreciably the same whether air is present or absent. It is the greater the higher the temperature, but rises in a much more rapid ratio. It is but rarely that the air contains this maximum quantity, except in cloud or fog, and it is then said to be *saturated*, whatever may be the temperature. If the air is below saturation, the quantity of vapour in it is expressed as a percentage of that required to saturate it at the actual temperature. This percentage is called its *relative humidity*, and it is upon this ratio that what we term its dryness or dampness chiefly depends; for the same quantity of vapour that would saturate the air or represent 100 per cent. of humidity at a temperature of 50°, would represent only 30 per cent. of saturation (a very dry atmosphere) at a temperature of 85°.

The *absolute* quantity of vapour present in the air may be expressed either by the number of grains in each cubic foot, or by the temperature at which it would just suffice to saturate it. This latter is termed the *dew point*, because, if a mass of air is gradually cooled down, it begins to deposit some of its vapour either as a dew or fog as soon as it reaches that temperature. Thus, in the case above given, the temperature of the air being 85° and its relative humidity 30, the dew point will be 50°. A third and still more common mode of expressing the quantity of vapour in the air is in terms of its tension or the elastic pressure that it exercises, measured in the same way as the pressure of the air, *i. e.*, barometrically. This is termed the *vapour tension, pressure* or *elasticity.*

It has been ascertained experimentally, by introducing a few drops of water into the Torricellian vacuum of a barometer, and measuring the depression it produces at different temperatures. The latest and most trustworthy tables of vapour tension are those based on Regnault's determinations. Such a table, computed for use in India from Regnault's data, is given in the accompanying collection of tables [Table III].

60. Hygrometers.—The instruments chiefly used for measuring the vapour in the air are Daniell's and Regnault's hygrometers, and Mason's hygrometer, also called the psychrometer. There are others, such as De Saussure's hair hygrometer; and the drying tube, the object of which last is to extract the vapour from a measured volume of air and to weigh it; but the former is not used in India, and the latter is too tedious in use for ordinary meteorological purposes. They are both described in Ganot's and Deschanel's physical handbooks.

61. Daniell's hygrometer.—The object of this instrument is to show the temperature of the dew point by cooling down the air in contact with it till dew is deposited. It consists of two glass bulbs, (one of black glass), connected by a large tube bent twice at right angles. The limb above the black glass bulb is longer than the other, and contains a small thermometer to show the temperature of the fluid (ether) which the bulb contains. The colourless glass bulb is covered with a piece of muslin. In constructing the instrument, the ether which it contains has been brought to the boiling point to drive out the air, and the tube has then been hermetically sealed. In order to take a dew point observation, all the ether is passed into the black bulb, and the instrument is then placed on its stand. The muslin-covered bulb is next moistened with a few drops of ether, which rapidly evaporates, cooling down the bulb and condensing the ether vapour within it. This causes more vapour to be given off from the black bulb, which in its turn is cooled down; and, by repeating the process, the temperature of the latter is lowered, until a ring of dew appears on the black surface of the bulb. At the instant that this is seen, the thermometer within is rapidly read off to the nearest tenth of a degree. The instrument is then allowed to stand and to absorb heat from the atmosphere and from objects around. At the instant that the dew ring disappears, the internal thermometer is again rapidly read off, and the mean of the two readings gives approximately the dew point. To obtain it accurately, the experiment should be slowly repeated.

62. Precautions.—In observing with Daniell's, and also with Regnault's hygrometer, great care must be taken to avoid breathing on the instrument, or to allow the hand or face to approach it so nearly as to bring it within the influence of the evaporation from the skin. The air around should be still; so that observations are best made in a verandah

or room communicating freely with the outside air, but without any strong draught. The instrument is not adapted for use in very dry climates. Colonel Sykes in the Dekhan and Dr. Forbes Watson in Ráj-pútána both failed to obtain the dew point of the dry atmosphere there prevalent in the hot weather. For such climates, Regnault's hygrometer is required.

63. Regnault's hygrometer.—The principle of this instrument is so far identical with that of Daniell's, that it consists in artificially cooling down a polished surface in contact with the air, by the evaporation of ether, until the temperature of the dew point is reached. But the means employed are more rapid and powerful, and a lower temperature can be readily produced. The instrument is, therefore, well fitted for use in very dry climates.

In its present form, as constructed by Casella, it consists of a thin metal capsule of the form of a large thimble, having a highly polished silver surface, and closed by a cork or stopper. Through this stopper passes the stem of a thermometer, the bulb of which is immersed in the ether with which the capsule is rather more than half-filled. A small metal tube passes down inside the capsule, and opens close to the bottom. To its upper end is attached a piece of India-rubber tubing, with a mouth piece, through which air is gently blown and made to bubble up through the ether. The current of air compels the rapid evaporation of the ether; the vapour of which, with the air, passes out of the vessel through another tube, the orifice of which is immediately below the stopper. By this means, the temperature of the ether is very rapidly reduced; and since the evaporation goes on from the very bottom of the fluid, and the whole mass is stirred up by the passage of the air bubbles, the cooling is equal throughout; the capsule is cooled at the same time; and, as soon as the dew point is reached, its highly polished surface is rendered dull by the deposited dew. The thermometer is then read off rapidly. The first observation will probably give only an approximate reading, since the thermometer falls very quickly; a second and third experiment, made more slowly, will give it accurately to the tenth of a degree.

So rapid is the action of this instrument, that in some observations made by the author at Secunderabad, at a temperature of 93° and with a dew point of 51°, representing a relative humidity of 24, six observations were made in a space of six minutes, and at Bellary, at a temperature of 96·1° and a dew point of 47·8 (equal to a relative humidity of 19), five observations were made in the space of ten minutes.

64. Mason's hygrometer or August's psychrometer.—The instruments above described have the advantage of determining the quantity of vapour in the air by direct methods. But they are not adapted for general use; being expensive, and requiring also some little skill in mani-

pulation. Mason's hygrometer gives an indirect indication only, but its use is simple, and, being self-acting, an observation consists simply in reading off a pair of thermometers.

It consists of two thermometers, one of which shows the temperature of the air, the other the temperature of an evaporating surface. This latter has a piece of muslin tied closely over the bulb and kept constantly wet by a bundle of cotton threads, which dip into a small vessel of water. The water is sucked up by the thread in the same way as oil is sucked up by a lamp-wick, and, spreading through the muslin, evaporates from the surface of the latter, with greater or less rapidity, according as the air is relatively dry or moist.

65. Principle of wet bulb.—Most persons are acquainted with the action of a wetted tatty in cooling the air that passes through it, and also with the common mode of cooling water by hanging a vessel of it surrounded by a wet cloth or damp straw in a shady place, exposed to a hot dry wind; or, what amounts to the same thing, in a vessel of porous earthenware, the outside of which is kept constantly wet by the water soaking through from within. In all these cases, coolness is produced by the evaporation of the water; and the faster the water evaporates, the greater is the cold produced. Thus it is with the wet bulb of the hygrometer; it is cooled by evaporation, and the temperature falls the lower, the more rapid the evaporation. The dry bulb thermometer shews the actual temperature of the air; and the difference of the readings of the dry and the wet bulb increases with the rate of evaporation, and this again increases with the dryness of the air. It does not, however, increase in the *same* ratio at different temperatures, nor is the wet bulb ever cooled down to the temperature of the dew point.

In computing the dew point from the depression of the wet bulb, it is assumed that the air around the bulb gives up heat sufficient to evaporate the additional quantity of water requisite to saturate it; and that, this atmosphere being constantly renewed, the wet bulb is kept at the temperature to which it is thus depressed.

66. Precautions.—It follows from the above that the air around the wet bulb must not stagnate. A gentle current should at all times pass across the bulb; and this conclusion from theory is borne out by observation. In a still atmosphere, as, *e. g.*, in a room, the wet bulb gives a reading higher than that supposed by the theory, and the humidity calculated from such an observation is too high. In the thermometer shed, the conditions are, in general, those required for good observation; but, if the air is quite calm, the wet bulb should be fanned by a hand punkha before the reading is taken. Under any circumstances, the sling thermometer, used as described in §33, gives a good result.

Distilled water or clean rain-water only should be used for moistening the bulb. River, tank, and spring-water contain salts which, on the evaporation of the water, are left encrusting the bulb and forming a stony deposit, which destroys its sensitiveness. In most parts of India, a supply of rain-water is easily procured and stored for use. In Sind and the drier parts of Rájpútána and the Punjáb, where no other than river or well-water is procurable, a supply of water should be well boiled and then allowed to stand before being used; and the bulb of the thermometer must be frequently examined and cleaned by the use of acid and careful scraping with a *sharp* pen-knife; but this requires great care. Observations made with an encrusted bulb are only misleading.

A small bottle with a narrow neck (to prevent useless evaporation) is the best form of reservoir. Keep it always full or nearly so.

Place the bottle with the neck a little on one side of the thermometer and about half an inch *below* it. [See Plate I.]

The bulb must always be well wetted. The muslin and thread must be washed at least once a week, and removed and renewed once or twice a month. Care must be taken that neither the muslin nor thread is greasy, but that they absorb water freely. If, in dry weather, the wet and dry bulbs give the same or nearly the same reading, the former is not properly wetted.

The muslin must be thin and fit closely to the bulb, and the wick that supplies it with water must be sufficiently thick to supply it freely. A strip of muslin, loosely twisted, is a good substitute for the wick.

67. When the wet bulb freezes.—At hill stations in the winter time, the wet bulb not infrequently falls below the freezing point. When this is the case, the water in the supply wick is frozen, and the bulb soon dries. It is then necessary to dip the bulb in water and to allow a film of ice to form *half an hour before* each observation is taken. After being dipped, the first film should be allowed to freeze, and a second dipping will produce a film of ice thick enough to last till the time for observing the depression.

In reading the hygrometer, the same precautions are to be observed as in the case of the thermometer. [See §28.]

68. Computation of vapour tension and the dew point.—Two formulæ, both based on the assumption specified in §65, are in use for this purpose.

69. Apjohn's formula.—That most frequently used in England was originally proposed by Dr. Apjohn, after whom it is called, and is as follows:—

$$(a) \quad F = f' - \frac{t-t'}{88}\,\frac{h}{30} \text{ or}$$

$$(b) \quad F = f' - \frac{t-t'}{96}\,\frac{h}{30}$$

when F is to the vapour tension at the dew point; f' that of saturated vapour at temperature t'; t the observed temperature of the dry, and t' that of the wet bulb thermometer; and h the height of the barometer (reduced for temperature) at the time of reading. The formula (a) is to be used if t' is above 32°, and formula (b) if below it. The value of f' is found in a table of vapour tensions, of which Regnault's and those based on his determinations are the most accurate [Table III]. When F has been computed, the same table is referred to, and the temperature at which F is the tension of saturated vapour is that of the dew point.

70. August's formula.—The other formula is that proposed by August, the constant values of which have been since corrected by the results of Regnault's determinations[a]. In its abridged and simplified form, omitting certain terms which affect the result but slightly, and adapted to Fahrenheit temperatures, it is as follows:—

$$F = f - \frac{0{\cdot}480\ (t - t')}{1130 - t'}\ h$$

for all *wet-bulb* temperatures above the freezing point, and for those below it—

$$F = f - \frac{0{\cdot}480\ (t - t')}{1240{\cdot}2 - t'}\ h$$

Tables calculated by this formula for the barometric pressure $h = 29{\cdot}7$ inches will be found in Guyot's *Meteorological and Physical Tables* published by the Smithsonian Institute at Washington; and Tables adapted to the mean latitude of 22° and the mean barometric pressures 29·7, 27·7, 25·8, and 23·4 are given in the collection of Tables which accompany this hand-book [Tables IV, VI, VIII and X]. These may be used for stations at all elevations up to 8,000 feet without serious error.

71. Glaisher's factors.—Mr. J. Glaisher has endeavoured to save observers some of the trouble of computation, by determining empirically certain factors, which, multiplied into the difference of the wet and dry bulb thermometers, will give the difference between the temperature of the air and that of the dew point. The result is approximately correct for high and moderate humidities, and for stations at and near the level of the sea; but the factors cannot be used for elevated stations, since they take no account of variations of pressure.

72. Comparison of different methods.—The results afforded by the above three methods agree only approximately, and it has long been a desideratum to compare them severally with the vapour tension of the dew point given by direct observation with Daniell's or Regnault's hygrometer. Some observations made with that view by the author

[a] For the rational development of this formula the reader may refer to the translation of Regnault's paper in Taylor's Scientific Memoirs, Vol. III, or to the original in the *Comptes Rendus* for April 1845.

at Secunderabad, Bellary, Coimbatoor, and Trichinopoly in April 1875 seem to shew that August's formula, as given above, is the most trustworthy. The observations were made in the thermometer sheds at the stations mentioned, where therefore the wind could act on the psychrometer. The temperatures varied from 92° to 97° in the shade, the dew points from 46·5 to 54·2, and the relative humidities from 18 to 26. The mean of 10 sets of observations computed by Apjohn's formula gave a mean error of +4·8°, Glaisher's factors one of +3·4°, and August's formula one of +1·0° only. The three methods require further testing, but meanwhile August's formula appears to give the best results.

73. Computation of relative humidity.—The vapour tension at the dew point having been ascertained as above, the relative humidity is computed by the formula $H = \frac{F \times 100}{\mathrm{F}}$; wherein, F is the vapour tension at the dew point, and F that of saturation at the temperature shewn by the dry bulb thermometer.

When a table of vapour tensions has been computed for any station for the required range of readings of the dry and wet bulbs, a table of humidities is easily calculated therefrom for the same mean pressure. [See Tables V, VII, IX and XI.]

74. Self-registering psychrometers.—Self-registering maximum and minimum thermometers may be fitted up as wet bulbs to record the highest and lowest temperature of evaporation during the day. The latter is an important adjunct to the record, as the lowest evaporation temperature, as a rule, coincides nearly with the lowest reading of the dry bulb and also with the time of *maximum* humidity of the day. The maximum wet bulb is, however, of little use, as, in the dry climate of Upper India, the highest temperature of evaporation frequently falls some time in the morning or evening, and rarely at the same time as the maximum of air temperature.

75. Corrections of instruments.—The corrections of the thermometers employed as hygrometers are to be applied to their readings before the latter are used to compute the humidity, &c. Both thermometers are to be read to the nearest tenth of a degree; and in using tables of vapour tension and humidity, values for fractions of a degree are to be obtained by interpolation, as described in the directions prefixed to the Tables.

RAIN-GAUGE.

76. Object and principle.—The object of the rain-gauge is to show the quantity of rain that falls. This is expressed in inches and decimal parts of an inch; the meaning being that, if the rain were to fall on a level surface which does not absorb it, and from which it cannot run off or evaporate, it would form a sheet of water so many inches or parts of an inch in depth.

77. Construction.—The instrument consists essentially of a funnel with a square or round mouth, and a receiving vessel. The quantity of rain received is determined by *the area of the mouth of the funnel;* and this area, if the rim of the funnel is round, is equal to the square of half its diameter multiplied by 3·1416. Thus a circular funnel, 4 inches in diameter, has a receiving area $(\frac{4}{2})^2 \times 3{\cdot}1416 = 12{\cdot}5664$ square inches. One six inches in diameter $(\frac{6}{2})^2 \times 3{\cdot}1416 = 28{\cdot}2744$ square inches, &c. Any change in the form of the opening, (such as may be produced by a blow or a squeeze,) diminishes its area, and the gauge will no longer register truly, and must be rejected. To provide against any accident of this kind, the rim of the funnel is generally strengthened by a stout brass ring.

The reservoir is either a large bottle, or a vessel of sheet zinc or copper, or tin plate; but this last is objectionable, being liable to rust. The water received is measured either in a graduated glass measure, or by means of a dip stick; or a light graduated rod, carried by a float which rises as the water accumulates. Some gauges are provided with certain mechanical arrangements for recording the rainfall on a dial, but these need not be described here.

Those with a graduated glass measure are all alike in the essentials of their construction, differing only in shape, dimensions and certain other details; and bear the different names of their inventors, as Symons' gauge, Glaisher's gauge, &c. The float gauge is generally known as Fleming's gauge. It will be necessary to notice those only that are in common use in India.

78. Symons' gauge.—This is the most convenient and trustworthy form of gauge, and is now used exclusively throughout Bengal and in some other provinces. It is a small cylindrical gauge, five inches in diameter and fourteen inches high. The water is received in a large glass bottle, and it is measured in a cylindrical glass, holding a quantity which represents an inch (or half-inch) of rainfall when filled up to a certain fixed mark. The space below is graduated in tenths and hundredths of an inch.

The gauge, as made in England, is intended to stand on the ground, or to have the bottom buried to the depth of two or three inches. In Bengal it is furnished with a foot of the form shewn in the figure, (Figure 10,) which gives it a firm hold in the ground and preserves it from the danger of being blown over. It is to be buried to the line A B.

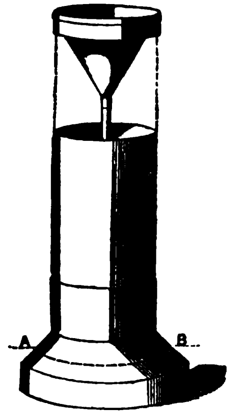

Figure 10. Symons' rain-gauge.

To measure the rain, lift the inner receiver and pour the rain cautiously, (so as to spill none) into the measuring glass, placed on a large empty dish. The glass will hold one inch. If more than one inch have fallen, the glass must be filled exactly to the one-inch mark, then emptied and re-filled, until all the rain collected has been measured. The pouring requires some care, and should be done over a large dish to catch any that may accidentally be spilled. The receiver (if of metal) should have a small lip or spout to facilitate pouring. The measure glass belonging to a rain-gauge is graduated for a receiving surface of definite dimensions, and cannot be used for a gauge of different diameter without a special calculation. A glass graduated for use with a 5-inch gauge may be used for any gauge of that diameter, but not for a 4-inch nor an 8-inch gauge. On an emergency, rainfall may, of course, be measured in any graduated glass, the exact capacity of which is known; but every reading in a register so kept must be reduced by calculation, the data for which are,—the diameter of the gauge funnel, its form whether round or square, and the value of the graduation either in cubic inches or fluid ounces. The latter may be converted into cubic inches by multiplying by 1·733, and this product divided by 3·1416 times the square of half the diameter of the funnel in inches, if the funnel be round, will give the depth of the rainfall. This rule may be useful at stations where a broken measure glass is not easily replaced without delay, since an ordinary apothecary's fluid measure glass can generally be procured for temporary use.

79. Glaisher's gauge.—This is similar to Symons' gauge, but is larger, *viz.*, 8-inches diameter. It appears from the comparative experiments made at Calne by a committee of the British Association, that this presents no advantage in point of accuracy over the smaller gauge. The spout at the base of the collecting funnel is bent, whereas that of Symon's gauge is straight; but this is rather a disadvantage, as it is more liable to become choked by the accumulation of dust, &c.

80. Fleming's gauge.—The receiver of this gauge is long and narrow, and contains a float (nearly as broad as the receiver,) carrying a light brass or wooden rod, which rises as the rain accumulates; passing through

a perforated bar across the mouth of the funnel. This bar serves as an index, and shows, by its intersection with the rod, the quantity of rainwater in the receiver. The float requires a certain quantity of water (variable in different gauges) to float it and bring it to the zero mark; and this quantity ought always to be kept in the gauge, a matter requiring some attention during dry weather. Failing this, the quantity required for flotation must be ascertained and added to the quantity read off. Should the rain be too small in quantity to bring the rod to the zero point, it cannot be accurately recorded. This gauge, therefore, in the hands of unskilled and inattentive persons, (and they are many,) is likely to give results always in defect of the truth, and such is found to be the case in practice.

The gauge is open to many other objections. If the float is dented or otherwise altered in form, or if any part has to be resoldered, the quantity of water required for its floatation is altered, and this is rarely if ever attended to. As this gauge, however, is still extensively used, attention is drawn to the following precautions:—

I.—Either enough water must be kept constantly in the receiver to retain the gauge at zero, (a troublesome matter in hot weather), or the gauge must be kept quite empty, and so much added to each reading as is required merely to bring the gauge rod to zero.[a]

II.—The gauge, being long, is liable to be blown over. It must therefore be placed in a wooden stand which is firmly bedded in the ground; or a metal cylinder or long wooden box of such size as to hold the receiver must be buried in the ground, and the receiver placed therein. In this case, the mouth of the funnel should be not less than one foot above the surface of the ground, to prevent dirt being blown or washed into it.

III.—In very heavy rains, as the cylinder will hold no more than six inches, the rain should be measured and the gauge emptied every three hours (or less), according to the quantity of the fall.

IV.—The gauge must be emptied after each observation, with due regard to the provision specified in I.

V.—The funnel which carries the index bar must be truly adjusted, and pressed home on the top of the receiver. This should be attended to before the reading is taken.

[a] This can be found by a simple experiment. Pour water into the empty receiver till the gauge is brought to zero. Pour it out again into an empty glass. Then, having poured a second portion of water into the receiver, and again brought the gauge to zero, return the first quantity into the receiver, and the gauge will shew the quantity it contained.

VI.—Sometimes the float does not rise freely, but either sticks in the receiver or is detained by the friction of the rod against the index bar. Before taking the reading the float rod should be lifted with the finger and thumb and then allowed to fall freely and adjust itself to the point of free flotation.

81. Site for rain-gauge.—This is a matter requiring some judgment. First the gauge should always be *on the ground*, and not on a building of any kind; unless more than one gauge are registered, and it is especially required to know the quantity collected at a certain elevation. This is always less than on the ground, and the variation is especially rapid within a few feet of the ground. In the experiments made at Calne, under the superintendence of a committee of the British Association, in the years 1863 to 1867, with gauges at different elevations, it was found that a gauge with its mouth on the level of the ground gave, on the average of the 4½ years, 6·7 per cent. more than one with the mouth one foot above the ground, and a gauge at the height of 20 feet gave nearly 5·7 per cent. less than the latter. It is, therefore, necessary, in order that the results may be comparable, that the same elevation should be universally adopted. That recommended, and now generally adopted, is that the mouth of the gauge be *one foot above the ground level*. The common practice of setting the gauge on a pillar of brick-work is a violation of the rule, and should be abandoned.

2nd.—The gauge must be as far as possible from trees, buildings, and all objects that dominate it; both that it may receive its full quota of rainfall with the wind from any quarter, and also that it may not receive droppings from trees, &c., when wind accompanies the rain.

WIND-VANE AND ANEMOMETER.

82. Construction of wind-vane.—A wind-vane, which shows the direction only of the wind, scarcely needs detailed description. The ordinary form is a balanced lever; one end of which exposes a broad surface to the wind, while the other is narrow, and serves to point the direction *from* which the wind blows, and therefore that by which the wind is designated. In ordinary wind-vanes, the vane alone revolves, and the vane rod bears a fixed cross immediately below the vane, the arms of which indicate the four cardinal points. By comparing the pointer of the vane with these, its direction is estimated with ease and with sufficient exactness.

83. Compass notation.—The notation universally adopted for registering wind directions is that of the mariner's compass, or numbers from 1 to 32, corresponding to the 32 compass points. Registration in degrees of arc is resorted to only to express the mean or resultant direction of a large mass of observations.

The following are the names of sixteen compass points with their respective letter symbols and numbers. The intermediate points, north by east, north-east by north, &c., are not required in general for wind registration:—

North	N.	32
North North-East	N. N. E.	2
North-East	N. E.	4
East North-East	E. N. E.	6
East	E.	8
East South-East	E. S. E.	10
South-East	S. E.	12
South South-East	S. S. E.	14
South	S.	16
South South-West	S. S. W.	18
South-West	S. W.	20
West South-West	W. S. W.	22
West	W.	24
West North-West	W. N. W.	26
North-West	N. W.	28
North North-West	N. N. W.	30
Calm	C.	

84. Calms.—If there is insufficient wind to move the wind-vane, the position of the vane is not to be recorded; but, in lieu thereof, the

letter C, indicating a calm. The anemometer will also show whether a wind direction or a calm should be entered on the register. If the cups are motionless, or only moving slowly at intervals, with intervening pauses, a calm should be recorded.

85. Dial vanes.—The wind-vanes, supplied to some of the meteorological stations, are made with the vane firmly keyed to the vane rod, which is so suspended as to revolve with the vane; and, passing through the roof (of the house on which it is fixed) to the room below, shows the direction of the vane on a fixed dial, by a pointer keyed on the rod, and exactly parallel with the pointer of the vane above. The advantage of this form is, that it may be read at night as accurately and conveniently as by day.

86. Choice of site and fixing.—In selecting a place for the wind-vane, the following points must be attended to:—

1. The place selected must be as open as possible, and there must be no object loftier than the wind-vane for a long distance (as far as possible), around. Large trees and buildings in the neighbourhood are always objectionable. Even if not lofty enough to screen the vane, when the wind blows from their direction, they nevertheless serve to cause eddies, such as may frequently be noticed in streets, and among buildings, which act on the vane from a direction different from that of the general current.

2. The vane must be fixed on the highest accessible point. If on a building, it should be fixed on the highest point of the building and at least four feet above it. It must, however, be easily accessible for the purpose of oiling, &c.

3. Its cardinal points must be set by compass, (and not by guess,) to true, (not magnetic) north. The declination of the compass (or difference between magnetic and true north) is very small in any part of India, not exceeding 2°, and magnetic north is east of true north. This variation, small as it is, must not be disregarded; for it must be borne in mind, as an universal law, that all errors which are constant in direction, however small and however roughly approximate the observations into which they enter, are reproduced to their full and true amount when the average of a very large number of observations is taken.

87. Beaufort's scale of wind-force.—In the absence of any instrument for registering the pressure or velocity of the wind, this, after some practice, may be estimated in such a manner as to give a useful record, and expressed in the scale of numbers proposed by Admiral Beaufort. These for stations on land are as follow:—

Calm	0
Light wind	1
Moderate	2

Fresh	3
Strong	4
Heavy	5
Violent (hurricane)	6

88. Pressure gauges and anemometers.—There are two classes of instruments in common use; one intended to show the pressure of the wind on a surface of constant area; the other designed to show the rate of its movement, or rather the actual distance travelled by it.

The former class comprise such instruments as Lind's and Osler's wind-gauges; the latter such as Whewell's, Robinson's, Casella's and Beckley's anemometers. Each of these will be briefly described.

89. Lind's wind-gauge.—This consists of a glass tube bent in the form of the letter U, and partly filled with water. Both limbs are open above, and one of them is bent round at top into a horizontal position, so that the opening may face the wind. This open end is sometimes furnished with a trumpet-shaped head with a view to enlarge the area of the opening on which the wind acts. The tube is attached to a broad vane and poised on a pivot, so that the opening is constantly presented to the wind. The pressure of the wind on the air which fills the upper part of the tube, between the opening and the water, is transmitted to the water, which is therefore depressed in the proximal limb and raised in the distal limb, and the difference in the height of the two columns indicates the pressure of the wind. This is read off on the gradation, which in the proximal limb is carried below the level of normal equilibrium, in the distal limb above it. This instrument, of course, serves to show the pressure, only at the moment of observation.

90. Osler's wind-gauge.—This instrument is autographic and serves to record the pressure and direction of the wind in all their variations. It consists essentially of a square plate, behind which are springs; whose elasticity serves to measure the force of the wind. This apparatus is attached to a large vane, which keeps the pressure plate at all times facing the direction from which the wind blows. To the back of the plate is attached a chain, passing over a pulley in the hollow spindle which carries both the vane and plate, the other end being fastened to a copper wire, which passes down the spindle and communicates the motions of the plate to a pencil, which traces a line on a sheet of ruled paper. The lower end of the spindle also communicates its movements, by means of suitable gearing, to a second pencil, which marks the direction of the wind on the same sheet. The record sheet is pinned to a flat board, which is made to travel horizontally beneath the pencils by means of clock-work; and the sheet is ruled in three divisions, one for recording the pressure, a second for direction, and a third, which receives the trace of a third pencil, registers the rainfall received by a gauge

beneath the anemometer. A full description of this instrument with figures will be found in Drew's *Practical Meteorology*.

91. Robinson's anemometer.—This instrument, which is now generally used at observatories, records the movement of a revolving vane by means of a train of toothed wheels; and the total movement is read off periodically on a dial, or on the wheels themselves, which are stamped with figures indicating tenths of miles, miles, tens and hundreds of miles. There are several forms of the instrument, differing in the arrangement of the wheels and the number and divisions of the recording dials. Some of the older instruments indicate the number of revolutions of the vane, from which the distance in miles must be computed.

The revolving vane is similar in all, and this is the essential part of Dr. Robinson's invention. It consists of four arms radiating horizontally in the form of a cross, and carrying four hemispherical cups of thin sheet copper. While revolving, these present alternately their concave and convex faces to the wind, and Dr. Robinson has shown by calculation, that, in virtue of the form of the two surfaces, the pressure of the wind on the former is to that on the latter, as 3 to 2. Consequently, the vane revolves with one-third of the velocity of the wind. This, however, is practically the case only with large instruments, the arms of which are two feet and upwards in length; and, in all cases, a correction has to be applied for friction, &c., which varies with each instrument, and must be determined by experiment. Small instruments always show a movement lower than that of large instruments, and less than that indicated by the theory.

In the ordinary small instruments, the revolution of the spindle which carries the revolving vane is communicated by an endless screw to the train of recording wheels. [Figure 11.] In front of each wheel is a fixed pointer, which indicates the reading of that wheel. Each wheel is divided into tenths, and the divisions are numbered from 0 to 9. There are generally five of these: the first, (moved directly by the spindle,) merely serves to communicate motion to the rest, and is unnumbered. The second indicates tenths of miles, the third whole miles, the fourth tens of miles, &c. Thus, one division of each wheel corresponds to a whole revolution of the wheel next below it.

92. Reading.—In reading off the wheels of the ordinary instruments above described, always take the lower of the two figures on opposite sides of the pointer; observing that, as 0 succeeds 9, 9 is the lower figure in the sense of this direction. If the pointer happens to be nearly over one of the figures—since these instruments are not always constructed with great nicety—a little precaution is necessary. In such case look at the wheel for the next *lower* value, and see whether its zero has passed the pointer or not. If it has passed, then the figure below

the pointer of the first wheel is to be recorded, with the lower figure of the second. But if the zero of the second wheel has not passed its pointer, it is to be concluded that the revolution is not complete, and therefore a whole division of the next wheel above it is not complete; so that, on this wheel, not that figure which is beneath the pointer, but the next below it must be taken.

Figure 11. Train of wheels in anemometer.

In the figure appended the reading will be 073·8 miles. In the instrument from which the woodcut was engraved the highest wheel appears to be at least one tooth out of position.

These anemometers usually register up to 1,000 miles. When a reading is made, if the amount of the previous reading is deducted, the difference shows the movement of the air in the interval; and this, divided by the number of hours that have elapsed, gives the average rate per hour. When the whole train of wheel work has completed a revolution in the interval, the last reading is to be deducted from 1,000 miles, and the remainder added to the amount of the actual reading.

93. Improved dial anemometer.—In this instrument, for the train of wheels, each of which is a dial, is substituted a pair of wheels on the same axis. The front wheel of the two bears an engraved dial with two divided scales, and the readings are indicated by two pointers, one of which is fixed to the outer case of the instrument, the other is carried by the hinder wheel and revolves with it. The fixed pointer indicates the division on a circle graduated from 0 to 5 miles, the miles being divided into tenths; and a complete revolution of the dial wheel therefore indicates five miles of wind. This pointer serves to show distances under five miles. The hinder wheel has one tooth less than the dial wheel; so that, at each revolution, the pointer carried by it advances on the dial wheel through the space of one tooth. This corresponds to one division of the outer circle, and therefore to five miles. There are 101 divisions making 505 miles, (in some instruments 100 divisions equal to 500 miles,) which therefore is the maximum distance registered by this form of anemometer.

94. Reading.—This is very simple. All distances *above* five miles are read off by the position of the moveable pointer on the outer circle;

the division next behind the pointer being taken. To this is added the amount indicated by the fixed pointer on the inner circle. When, in the interval of two readings, the moveable pointer has passed the zero, the last reading is to be deducted from either 505 or 500 miles (according to the graduation of the instrument), and the remainder added to the actual reading. The reading of the dial represented in Figure 12 is $285 + 1{\cdot}5 = 286{\cdot}5$ miles.

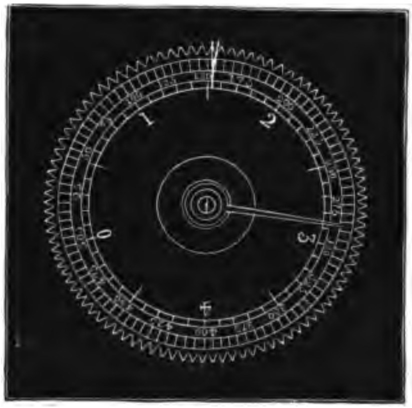

Figure 12. Anemometer dial.

95. Beckley's anemograph.—This is an instrument on the principle of Robinson's anemometer, which records the direction and movement of the wind continuously on a sheet of metallic paper. The direction is obtained by means of a pair of wind-vanes on the principle of the windmill regulator. These are set on the same axis, and are set in motion by the wind, until they are presented to it edge-wise, when they cease to revolve. Their axis carries an endless screw, which works into a toothed disk [see Figure 13] fixed to the cast-iron standard of the instrument. The frame which carries the vanes and screw is firmly attached to a disk-shaped cover of cast iron, from which a hollow cylindrical shaft passes down inside the hollow standard, and being supported on friction rollers, the whole is made to revolve by the motion of the vanes. At its lower end, inside a cast-iron box at the base of the standard, the shaft carries a toothed disk which communicates its motion to a light hollow brass rod ; and this in its turn works the recording apparatus presently to be described.

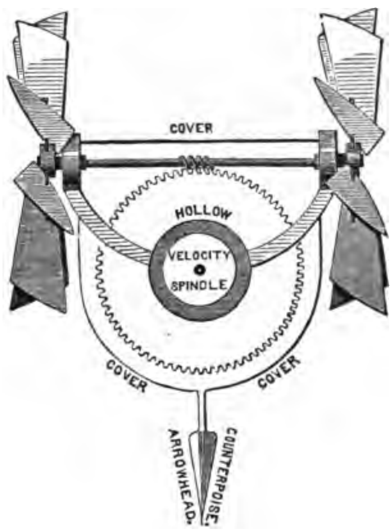

Figure 13. Direction vanes of Beckley's anemograph.

The distance travelled by the wind is obtained by means of Robinson's hemispherical cups, nine inches in diameter, carried on a frame of four arms, each two feet in length. The spindle, to which the cup-frame is keyed, passes down the axis of the hollow direction shaft, and by means of suitable gearing in the box at the base of the standard, communicates its motion to a second brass rod, which works the pencil cylinder in a room below.

The recording apparatus is placed in a room below the anemometer and consists of a clock, which turns a horizontal brass cylinder 4¼ inches in diameter. This completes a revolution in (two or) three days, and carries a sheet of metallic paper, fastened by clips, and lithographed with two ruled forms, the one for direction, the other for velocity. These forms are adapted for (one or) two days' registers, and are divided transversely into hour spaces duly numbered. The direction form is ruled longitudinally with lines corresponding to the eight principal compass points. That for velocity is divided into five spaces, each of which corresponds to a movement of ten miles, so that the whole width of the form corresponds to a trace of fifty miles. Above the cylinder are two rollers, each bearing a spiral plate, the edge of which presses on the recording sheet, and, with the least friction, leaves a mark on the metallic paper. These may be termed the pencil rollers. Now, the spiral pencil makes one turn in the width of the form ; and, if turned continuously, traces a line across the form, and then, coming into contact again at its further end, begins another line, which it carries across the form in like manner. But as, during this movement, the form-cylinder is being carried round by the clock work, the trace in the case of the velocity pencil becomes oblique, and the more so, the lower the velocity of the wind. The velocity pencil roller can revolve only in one direction, which is determined by that of the Robinson's cups and the intermediate gearing, while the direction pencil roller rotates one way or the other according to the veering of the wind.

The record sheet is adjusted to the cylinder by certain marks lithographed on the form. This being done, the arrowhead, which is carried by the direction disk, (Figure 13,) must be brought round by hand till it is directed to true north ; (which point must have been previously ascertained by compass or a meridian observation). The 'direction' pencil roller, having been thrown out of gearing by raising the bevelled toothed wheel on the driving rod, is then set, so that the spiral pencil is in contact with the north line lithographed on the register sheet, and in this position it is brought into gearing by depressing the wheel of the driving rod, till the teeth interlock with those of the pencil roller.

On removing the record sheet, the date, the hour and minute at which it was adjusted to the roller and removed, the name of the

observatory, &c., are to be entered on the form before it is put aside.

96. Casella's anemograph.—This instrument, like Beckley's, records the movement and direction of the wind, but in a different manner. The direction is determined by the revolution of an ordinary arrow-vane, the movement of which is communicated by gearing and an endless chain to a die, which, once in every hour, (or at shorter intervals, according to the construction,) stamps the direction on a strip of paper. The edge of the paper is embossed with figures indicating the distance travelled, by means of rollers which are set in motion by Robinson's cup and ball motor.

97. Whewell's anemometer.—This consists of a vertical fixed cylinder, the surface of which is covered with varnished paper, ruled with vertical lines, corresponding to the principal compass points; and must be adjusted to the proper direction, (the marked points diametrically opposite to the true compass points,) in fixing the instrument. A vertical spindle, passing through the axis of the cylinder, carries a horizontal brass plate, which is made to revolve with the wind by means of a fixed vane attached to its upper surface. It also carries a small windmill fly which is constantly presented to the wind and rotates with a velocity proportioned to the strength of the wind. The motion of the fly is communicated by an endless screw and suitable gearing to a long vertical screw beneath the plate, causing a pencil to descend gradually and trace a line on the cylinder, the vertical measurement of which is proportional to the wind's movement. As the screw and pencil revolve with the motion of the plate, the trace is produced on that side of the cylinder opposite to the direction from which the wind blows.

When the pencil has descended through the entire length of the screw, it is unclamped and raised to the top. The trace on the varnished surface of the cylinder is measured and recorded, and then washed off.

This anemometer does not, like Beckley's and Casella's instruments, indicate the time at which the wind was blowing from any quarter; but only the direction, and distance corresponding to each direction, with the order of the changes since the last observation.

CLOUD OBSERVATIONS.

98. Object of cloud observations.—No kind of meteorological observation is of more importance than that of the forms and movements of the clouds; but it requires some study and experience to know how and what to observe, and unfortunately there is no kind of observation that, in India at least, is less satisfactory than this.

The forms and movements of the clouds afford us the only information we can obtain of the changes in progress in any part of the atmosphere above the very lowest stratum; for it is only that stratum which rests immediately on the earth's surface that we can probe and analyse, and whose motions and conditions we can study by means of the instruments already described.

In the first place, the very existence of a cloud at any elevation is an indication that the atmosphere is there in a state of saturation; and the lower the cloud, the more humid (relatively humid) is the atmosphere. In the second place, the forms of the clouds may give information as to the changes of temperature and the cause of these changes; and thirdly, their movements show what winds are blowing high up in the atmosphere, and even the rate of their movement. If indeed the height of the clouds is measured, they serve both as a wind-vane and anemometer, whose precision leaves little to desire.

Cloud observations, as usually made, include their quantity, form and movement.

99. Cloud proportion.—The proportion of the sky covered by clouds is estimated by simple inspection. A sky wholly overcast is recorded as '10' of cloud; and all minor degrees of cloudiness by the lower numbers, the figure '0' being used to indicate an unclouded sky. From the nature of the observation, an approximate estimate only is possible; but, with a little practice, it will be found easy to make it with sufficient accuracy for practical requirements. It may assist beginners, in making this estimate, to notice that, if the sky be supposed divided into five triangular segments by five equidistant lines drawn from the zenith to the horizon, each of these will be divided into two nearly equal parts by a line parallel with the horizon, and at one-third the distance between it and the zenith.

In making the estimate, clouds at a great distance, low and near the horizon, are not to be regarded.

100. Kinds of clouds.—It has been usual in meteorological treatises and registers, to adopt Luke Howard's classification of clouds, as

was indeed done in the original edition of this little manual. But, as Poëy, Fritsch, and Dr. Mann have pointed out, much confusion has arisen in the application of Howard's terminology, partly owing to defects in the original definitions, partly to the misconceptions of those who have adopted his system. In no case is this confusion more apparent than in the application of the term *stratus*. Howard's *stratus* cloud is simply fog, whether resting on the ground or at some very small height above it. But, misled by the pictorial representations given in illustration of the type, it is a common practice of observers to enter as '*stratus*' all clouds which appear as horizontal streaks near the horizon, and which being really high in the atmosphere are generally *cirro-stratus*. '*Stratus*' is an unusual cloud in India, except in the cold weather, in the damper parts of Bengal, and in the evening after sunset. Many of the objections to Howard's classification have been removed by Poëy, who, retaining certain of Howard's classes of clouds, has reclassified the others, without sacrificing the simplicity, but, on the contrary, adding to both the simplicity and definition of the system. Poëy classifies clouds as—

1. *Cirrus.*	5. *Pallio-cirrus.*
2. *Cirro-stratus.*	6. *Pallio-cumulus.*
3. *Cirro-cumulus.*	7. *Cumulus.*
4. *Pallium.*	8. *Fracto-cumulus.*

Of these, the first three and fifth are the higher clouds. The last three are the clouds of the lower atmosphere.

101. **Cirrus.**—This the most lofty of all clouds, appearing still at a great elevation, even when seen from the greatest heights of the Himalayas, and, as estimated by Fritsch, probably never lower than six miles. It consists of minute snow crystals forming feathery groups or brushes, parallel, diverging or curled, very thin, and always more or less fibrous in appearance.

102. **Cirro-stratus.**—Also a lofty cloud, but lower, denser and more sheet-like than *cirrus*. It is at such a height that it also consists of snow crystals, but is sometimes of such thickness as to dim the sun's disc, and even almost completely obscure it. When it does not extend over the whole sky it thins off towards the edges; and when seen, as sometimes in the evening and morning, low down near the horizon, it presents the appearance of horizontal streaks, which are often misinterpreted as *stratus*. Its form is very variable, sometimes it appears as a uniform sheet, at other times as broken, undulated or fenestrated layers. It exhibits the phenomena of lunar and solar halos.

103. **Cirro-cumulus.**—Also a lofty cloud, which forms on the breaking up of *pallio-cirrus*. One common form of it is known as a

mackerel sky, consisting of little rounded cloud tufts, more or less regularly arranged in ripple-like layers. Often appearing after rain.

104. Pallium.—Consisting of the two following.

105. Pallio-cirrus.—A thick, but lofty, sheet of cloud obscuring the sky, and forming the upper layer of the *pallium* or rain cloud. It is formed by the sinking and thickening of *cirro-stratus.*

106. Pallio-cumulus.—The thick mantle of cloud which constitutes the lower layer of *pallium* or rain cloud. Formed by the rapid increase and coalescence of *cumulus.* It extends to greater heights than ordinary *cumulus,* but is [sometimes?] separated from the higher layer of *pallio-cirrus* by a cloudless intervening stratum. After rain, it breaks up and disperses more quickly than the higher *pallio-cirrus.*

107. Cumulus.—This is one of the most familiar and typical of cloud forms, and is characteristic of the lower atmosphere. In Bengal nothing is more common, after a fine morning in the hot weather, and specially during breaks in the rains, than to witness the formation, at no great height, of isolated masses of clouds with rounded summits and flat bases, all at about the same level. These are *cumulus;* and mark the summits of ascending columns of air, which reach saturation (§ 59) at the plane marked by the bases of the cloud patches; and, above this, deposit the excess of their moisture as cloud.

108. Fracto-cumulus.—The broken, irregular, masses into which *pallio-cumulus* is resolved when in the act of breaking up, or into which it is riven by the wind. It is therefore, like *cumulus,* a cloud of the lower atmosphere, and includes the torn masses commonly termed "scud."

109. Cloud symbols.—In recording the cloud forms in the regular register, the following symbols afford a convenient abbreviated notation :—

C *Cirrus.*	Pc *Pallio-cirrus.*
Cs *Cirro-stratus.*	Pk *Pallio-cumulus.*
Ck *Cirro-cumulus.*	K *Cumulus.*
P *Pallium.*	Fk *Fracto-cumulus.*

the first letter being a capital, the second a small letter in the case of bi-literal symbols. The symbol P indicates that the sky is overcast or nearly so by a low sheet of cloud in or about the altitude of *cumulus,* and concealing all above it. When the sky is overcast by a sheet of very elevated cloud, this may be either *cirro-stratus* or *pallio-cirrus,* the latter being the lower and denser of the two.

110. Movement of clouds.—This subject deserves more attention than has hitherto been given to it in India. There is but little difficulty in observing the direction of the movement; but, like other kinds of observation, if it be attempted as a mere matter of routine, and without some

care and attention, the register is likely to be so erroneous as to be only misleading and worse than worthless.

The besetting difficulty in obtaining a true estimate of the direction of the cloud movements is the elimination of the effects of perspective. It is very difficult, and indeed impracticable without the aid of some such instrument as the nephescope of Dr. C. Braun,[a] to estimate truly the direction of clouds which are not moving either directly towards or directly away from the observer; and this, therefore, is the condition to be secured.

Set up a pointed pole, reaching 6 or 8 feet above the observer's head; and through the top, an inch or two below the point, fix two stout cross wires or thin iron rods, set truly by compass to the four cardinal points. The space around the pole must be sufficiently open to allow of a good view of the expanse of the sky in all directions. Let the observer then station himself at such a distance from the pole and in such a position that some recognizable limb of a cloud appears to move vertically upwards from the top of the pole or vertically downwards towards it. The direction of the pole from the observer's position, (which may be judged of accurately by means of the cross wires on the top,) is the direction of the cloud's true movement.

With a little care in selecting the position, the pole may be dispensed with. Any pointed object will serve the purpose, provided the observer has previously acquainted himself accurately with the directions of the compass points.

In recording the direction of the cloud movements, the kind of cloud on which the observation is made, whether *Cirrus*, *Cirro-stratus*, *Fracto-cumulus*, or other, should be noticed by its appropriate symbol. This is necessary, since the kind of cloud observed affords a rough indication of the elevation to which the observation relates.

The velocity of the movement of a cloud may be measured in favourable situations by observing the time that the shadow takes to traverse a certain space of country the distance of which is accurately known.

[a] Described in the Journal of the Austrian Meteorological Society, 1867, vol. ii., page 337.

GENERAL WEATHER OBSERVATIONS.

Beaufort's initials and Vienna symbols.

111. In addition to the readings of the instruments, and such observations on the clouds as were explained in the last section, general observations on the appearance of the atmosphere and the occurrence of casual phenomena are a very important addition to a meteorological register. These observations should have reference not only to the regular hours at which the instruments are read, ***but also to the intervening periods;*** and, as far as possible, the time of each occurrence also should be noted in the register.

The principal facts to be recorded are—

1st.—The general appearance of the atmosphere and the sky during the interval preceding the observation, including the cloudiness, transparency or haziness of the atmosphere, such phenomena as coronas or halos round the sun and moon, any unusual coloration of the clouds, auroras, &c.

2nd.—The occurrence of dew, rain, hail, snow, dust-storms, thunder and lightning, squalls of wind or rain, hot winds, &c.

3rd.—The hour, or at least the approximate time, at which any of these took place.

112. Beaufort's initials and the Vienna Conference symbols.—The former of these have long been used by English meteorological observers. They have been supplemented by certain symbols, some of which have a similar signification, while others are unrepresented in the Beaufort notation. The following are such as will be of use generally in India, while those that have application only in a cold climate are given separately. One or two symbols have been added which are not included in the Vienna Code, but will be useful in India. The use and meaning of all that do not sufficiently explain themselves will be shewn more fully below :—

Symbols.	Initials.	
	b.	Blue sky.
	c.	Partial clouds.
	d.	Drizzling rain.
≡	*f.*	Fog.
	g.	Dark, gloomy weather.

Symbols.	Initials.	
▲	*h.*	Hail.
	l.	Lightning.
∞	*m.*	Misty, dust haze.
	o.	Overcast.
	p.	Passing, temporary showers.
	q.	Squally.
	t.	Thunder.
	u.	Ugly, threatening.
	v.	Visibility; referring to distant objects.
	w.	Wet, for dew.
		Thunderstorm.
		Hoar frost.
		Strong wind.
⊕		Solar corona.
○		Do. halo.
		Lunar corona.
		Do. halo.
		Aurora.

The following are new :—

Symbols.	Initials.	
		Dust whirl or 'devil.'
		Dust storm.
		Hot wind.

For cold climates, such as the hill stations in winter—

Symbols.	Initials.	
*	*s.*	Snow.
△		Soft hail.
V		Silver thaw.
~		Glazed frost.

113. **Blue sky** (*b*).—For a *cloudless* sky, whether the atmosphere be clear or hazy.

114. Clouds (*c*).—Either for clouds in detached masses, or in sheets with openings. Not to be used when the sky is overcast.

115. Fog (*f*).—Except among hills and in the cold weather in the damper parts of India, this symbol will not be much used. It is not to be used for mistiness, but only for such fogs as form over damp places in the evening.

116. Lightning (*l*).—Not to be used for the flashes that are sometimes seen to illumine the sky low down near the horizon. These, if noticed at all, may be entered as *lr* (lightning reflection).

117. Misty (*m*).—To be used for the dust haze so common throughout the dry season in the interior of India.

118. Overcast (*o*).—To be used when the sky is completely covered with pallio-cirrus or pallio-cumulus.

119. Passing showers (*p*).—Not for north-westers and similar storms, but for the case when showers, lasting for a few minutes, succeed each other with fine intervals.

120. Squally (*q*).—This initial, or the symbol for a strong wind, may be used for a north-wester, and that for a thunder storm may be used when, as is usually the case in Bengal, the north-wester ends in such a storm.

121. Visibility (*v*).—This symbol is very frequently misused. It has reference to the *transparency* of the atmosphere, and indicates that the details of distant objects can be seen with *unusual distinctness*. On the plains of India such a state is rarely experienced, except either immediately before, or immediately after, rain.

122. Hoar frost.—I include this in the symbols in general use, since hoar frost is tolerably common in the cold weather in certain parts of the Upper Provinces. It is simply dew deposited from air at or below the freezing point.

123. Coronas and halos.—These must be carefully distinguished. *Coronas* are very common, specially around the moon, and are produced by the rays passing through a thin layer of cloud. They are small circles around the luminary, as many as three concentric circles, with diameters in the ratio of 1 : 2 : 3, being sometimes seen at the same time. They are frequently coloured, red being the outside colour. These colours are not the pure colours of the spectrum, but rather those of the opal, or such as are seen in Newton's rings. They are interference, not refraction colours.

Halos are large circles of 46° and 92° in diameter, *i.e.*, the diameter of the circle is equal to either one-eighth or one-fourth the circumference of the horizon, or subtends either one-fourth or one-half the arc of the celestial vault. They are very rare phenomena, especially in India, but

have been occasionally seen from the Himalaya.[a] Solar halos are frequently accompanied by mock suns or *parhelia.*

The foregoing are of interest, rather as optical phenomena, than as affording important indications of processes of physical change in the state of the atmosphere. In this latter connection, the chief information afforded by them is the nature and consistency of the cloud on which they are projected; coronas being formed on water drops, halos only on snow crystals. Other optical phenomena of interest, as such, are, rainbows, fogbows or anthelia, mirage, &c., and the beautiful opal fringes of clouds, which may be witnessed not infrequently towards the evening, more especially in Bengal, in the hot weather and rains. All such phenomena are well worthy of observation and study; but, for information respecting them, the reader is referred to treatises of a less elementary and restricted character than the present.

124. Soft hail.—Small, soft, rounded, opaque, white pellets consisting of frozen snow.

125. Silver thaw.—Similar, in mode of formation, to hoar frost. A very dense deposit of long frozen needles, formed on the branches of trees.

126. Glazed frost.—When a thaw sets in, followed rapidly by a frost, the half-melted snow is refrozen, and covered by a film of ice presenting a glazed appearance and very slippery. This is termed "glazed-frost."

---

[a] See, *e. g.*, an account of one witnessed by Captain W. Sherwill at Darjeeling in 1852, Journal of the Asiatic Society of Bengal, vol. xxiii, 1854, p. 49. A figure accompanies the description.

HOURS OF OBSERVATION.

127. Regulating conditions.—Instruments, such as the barograph, thermograph, anemograph, &c., that record continuously, afford, of course, the most perfect record that can be desired of the march of the several atmospheric phenomena; but even these require to be controlled by eye observations, since even the best machinery has, or may have, inherent faults, which require to be ascertained and their effects eliminated; and, moreover, it is not always practicable to give the instruments the same kind of exposure which is practised in the case of smaller instruments. This subject will be noticed presently. Next to self-registering instruments, hourly observations are the most effective; but they can be carried out continuously, only where a large establishment of observers is available. Even occasional hourly observations, such as those recorded on four days in each month at the second class stations of the Indian meteorological system, are, however, a very valuable adjunct to a meteorological register, and, wherever practicable, they should be taken. But in most cases the question is,—what is the smallest number of observations that will serve a useful purpose, and at what hours should they be recorded?

This latter question was discussed at the Vienna Conference, and certain sets of hours adopted alternatively, to be left to the choice of observers. But they were framed with a view to the conditions of extra-tropical countries, where the diurnal march of phenomena is less regular and dominant than in India, and they are not, for the most part, adapted to the conditions which obtain in this country. Moreover, it is of great importance to preserve uniformity, and it is, therefore, desirable that the same hours be observed at all stations. The hours should be such as will shew, as nearly as possible, the average range of the principal elements, and also afford the means of computing their mean values.

128. The adopted hours.—These conditions are best fulfilled by adopting the hours of 10h. and 16h. (10 A.M. and 4 P.M.) *mean local* time (not railway time) for reading the instruments. These hours are, on an average, those nearest to the maximum and minimum barometric pressure of the day, and this is the chief reason for selecting them. The mean of the two gives an approximation to the mean pressure of the day, while their difference is the approximate range. The temperatures are both above the mean temperature of the day, but by using self-registering maximum and minimum thermometers, the 10h. and 16h. temperatures afford data, which, together with the former, allow of a near approximation to the mean temperature of the day, when cor-

rected in the manner to be explained in the next chapter [§ 139]. A similar remark applies, with less accuracy, to the hygrometric elements, if a minimum wet-bulb thermometer be also used. The observations proper to be recorded at each of these hours, are—

At 10h.	At 16h.
Barometer.	Barometer.
Dry and wet bulb thermometers.	Dry and wet bulb thermometers.
Minimum dry and wet bulbs.	[a] Maximum thermometer.
Grass radiation thermometer.	[a] Sun thermometer.
Anemometer.	Anemometer.
Wind direction.	Wind direction.
Cloud proportion, kind and movement.	[a] Rain measurement.
General weather.	Cloud proportion, kind and movement.
	General weather.

General weather observations should, however, be made also in the intervals. Thus, the occurrence of dew or fog or hoar frost should be noted in the early morning; rain, or a thunder or dust-storm, at the hour at which it occurs. Lunar coronas and halos must be looked for at night, &c. Meteorological observation can never be regarded as a mere mechanical performance. It requires intelligence, like most other work.

129. Additional hours.—If, in addition to the above, any other hours can be observed, the raingauge and maximum thermometers should be read at 18 hours. And, if an additional set of barometric and other readings can be taken, it is a very important addition to the register, to take them at 22 hours (10 P.M.).

130. Synoptic observations.—A system of synoptic observations has been started by General Mayer, of the U. S. Signal Service, which is now carried out in America, the British Isles and a great part of Europe, and which it is sought to extend all over the world. This is, to obtain observations made at the same absolute time, irrespective of the local time, all over the world. The Washington time is 7h. 35m. A.M. This is synchronous with Greenwich mean time 12h. 43m. The following are the corresponding hours of mean local time at some of the chief stations in India and its dependencies[b]:—

Kurrachee	17 h. 11m. P.M.	Bombay	17 h. 35m. P.M.
Deesa	17 „ 32 „ „	Poona	17 „ 40 „ „

[a] It is preferable to read these at 18h., as directed in the next paragraph.

[b] If the Madras time be deducted from that of the stations that follow, the remainder will shew how much the clock, set to local time at these stations, will be in advance of one set to railway time. And if, from Madras time, that of the stations that precede be deducted, the residue will shew how much a clock set to their local time will be behind one set to railway time.

Lahore	17 h. 40m. P.M.	Allahabad	18 h. 10m. P.M.
Belgaum	17 „ 42 „ „	Patna	18 „ 24 „ „
Bangalore	17 „ 53 „ „	Hazaribagh	18 „ 25 „ „
Roorkee	17 „ 55 „ „	Cuttack	18 „ 27 „ „
Agra	17 „ 55 „ „	Calcutta	18 „ 36 „ „
Trichinopoly	17 „ 58 „ „	Goalpara	18 „ 46 „ „
Nagpore	17 „ 59 „ „	Chittagong	18 „ 50 „ „
Jubbulpore	18 „ 3 „ „	Sibsagar	19 „ 2 „ „
Madras	18 „ 4 „ „	Rangoon	19 „ 8 „ „
Lucknow	18 „ 7 „ „		

The instruments to be observed are the barometer, dry and wet bulb thermometers, wind-vane, anemometer and raingauge; with observations on the quantity of the lower, and the direction of the upper clouds.

131. Importance of punctuality.—It cannot be too strongly impressed on observers that they must be strictly punctual to the hours assigned. The clock that regulates the observations must be kept at the true *local* time, and the observer should make it his business to be ready five minutes before the time, so that there may be no delay and irregularity. The whole process may take about five minutes, so that it is best to begin two minutes before the hour, and to read the instruments always in the same order. It depends on the Superintendents of Observatories to enforce regularity, seeing that laxity and unpunctuality are besetting sins, to which half-educated observers are especially liable. If an observer is unavoidably absent at the proper hour, it is better to omit the observations than to record them, perhaps, a quarter of an hour or twenty minutes after the proper time. A hiatus, however objectionable, is better than a deceptive entry.

132. Controlling observations.—Observations, the object of which is to control the registers of automatic instruments, (a thermograph, for instance,) should be taken about the times of maximum and minimum, and at as many intermediate periods as may be convenient. These should be repeated daily.

133. During storms.—During storms, the barometer is always greatly affected, and should be read, if possible, every 5 or 10 minutes, (together with the attached thermometer). The direction of the wind and the movements of the clouds should be observed also at short intervals; and, with the thermometer, hygrometer, and, if possible, the anemometer, recorded half-hourly or hourly.

When accompanied by very heavy rain, it is desirable to empty the raingauge, and to record its reading two or three times during the day.

REDUCTION OF OBSERVATIONS.

134. Reduction.—By the reduction of the observations is meant—*1st*, their correction for errors due to the imperfection of the instruments or their deviation from accepted standards; *2nd*, the elimination of effects which are not those we require to measure; *3rd*, the computation of certain elements which have not been observed directly, but which may be deduced from the observations; and *4thly*, the grouping of the results of the corrected observations in such a manner as may be most convenient for studying their relations to each other.

Under the *first* of these heads comes the correction of the index errors of barometers and thermometers, of the varying friction errors of anemometers, &c. Under the *second*, the correction of the barometer for cistern capacity and for temperature, and the deduction of the air temperature from that shewn by the sun thermometer, in order to obtain the differential effect of solar radiation. Under the *third*, the calculation of the barometric pressure at sea-level from the actual readings, and that of vapour tension and humidity from the readings of the dry and wet bulb thermometers. All these have been treated of, at sufficient length, under the respective headings of the several instruments and classes of observations; and it remains, therefore, only to deal with the 4th class of reductions, *viz.*, the grouping of the results; and these only to such an extent as is requisite for preparing the usual published statements of results. It is obvious that, for particular enquiries, the grouping of results may be indefinitely varied, and for such cases no general rules can be laid down: the intelligence of the investigator is then the only possible guide.

The most common form of grouping observations for publication is to give them as *mean* values for a day, month or year, with their extremes and range of variation.

135. Definition of mean values.—In ordinary language a *mean* is simply the arithmetical average of a number of specified values; but, as used in meteorological registers, something more than this is generally implied. It is not merely the average of the observations, but either the average of a *whole* day, a *whole* month or a *whole* year, and is understood to express the average value of *all* the variations that an element (such as pressure, temperature, &c.) undergoes from the beginning to

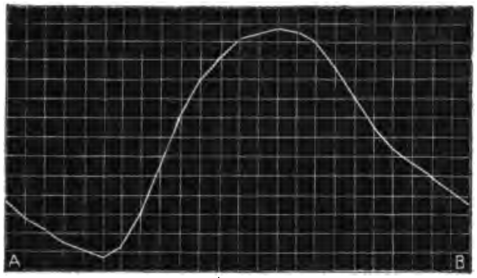

Figure 14. Diurnal curve of temperature.

the end of such period. To illustrate this geometrically:—suppose the line A B to represent a fixed temperature, say 70°, and the parallel horizontal lines above it represent successive increments of 1°. Let the vertical lines represent successive hours from midnight to midnight, and let us mark off on each of these a height representing the exact temperature of that hour. Draw a curved line through all these points, and it will represent the course of the changes of temperature throughout the day. The *mean temperature* of the day, so represented, will be the average, (not only of the hour lines represented, but also) of an infinite number of other vertical lines between them. Each of these being an ordinate of the curve, the mean temperature is represented by the mean or average ordinate of the whole curve. It is a line *such* that, if we draw a rectangle of *that* height on the base A B, the area of this rectangle shall be exactly equal to the area of the curved figure.

In order to ascertain this with great accuracy, it would be necessary to obtain a continuous trace of the temperature by some form of thermograph, and to measure the area comprehended between the curve and a fiducial base line. But for all practical purposes, it is quite sufficient to record observations at short and equal intervals of time, (generally an hour,) and to take the average of the whole. This was the practice at several first class observatories before the invention of self-recording instruments, and is still so at Calcutta. But it is very laborious, and would be impracticable where there is not a considerable staff of observers; and, therefore, various expedients are resorted to, to obtain something near this result from a smaller number of observations. It is, however, by no means a matter of indifference what observations we take and how we treat them. For instance, it is usual to observe the temperature at 10 A.M. and 4 P.M.; but, since at both these hours the warmth of the air is above the average of the twenty-four hours, the mean of these two observations would be much higher than the average which is required. The highest and lowest temperatures are also generally registered, but the mean of these is generally too high; since, as a general rule, the temperature ranges below the average longer than it ranges above it. Moreover, since the variation curves of pressure, tem-

perature, vapour tension, humidity, &c., are all different, a method that is applicable in one case is by no means so in another.

136. Method of six-hourly observations.—A method which, in principle, is similar to that of hourly observations, and, though inferior to it, gives results not very far from a true mean in the case of such elements as temperature, pressure, &c., is, to record observations four times daily, at equal intervals of six hours; and to take their average. The best hours for the purpose are 4 and 10 A.M. and P.M. Whenever this plan can be followed, *the proper hours being punctually adhered to,* it is the best substitute for continuous (autographic) or hourly registration; but, if this be not the case,—and it requires the stimulus of a deeper interest or a stronger sense of duty than is often to be met with to carry on such a system punctually and regularly,—it is better to content ourselves with methods less accurate in principle, but the conditions of which are more strictly fulfilled in practice.

137. Empirical methods.—These are very various. In order to apply them, we must first have ascertained the normal law of the variation, either from continuous registration, or from observations taken at short and equal intervals throughout the period of which the mean is required. This being known, (in the case of the diurnal period, for instance,) we know also how far a series of observations recorded at any given hour are *on an average* above or below the mean required; and, at least, twice every day the element in question is at its average value. The hours of average value are not, however, the same at different times of year, and an equally good result can be obtained by selecting hours that are otherwise convenient, and applying an average correction, which must be determined from the law of the variation. The method now adopted in the Meteorological Department is one devised by Mr. Pogson, and may be termed the method of range factors.

138. Pogson's range factors for pressure.—For the barometer, the use of these may be best explained by an example. Let it be required to determine the mean atmospheric pressure of any day from two observations of the barometer recorded at 10 A.M. and 4 P.M. at Házáribágh in the month of July. The average daily range of the barometer in this month at Házáribágh between 10 A.M. and 4. P.M. has been found to be ·0679 on the average of seven years. The 10-hour reading, on the same average, is ·0273 above the mean of the 24-hour, and the 4 P.M. readings ·0406 below it. The normal corrections for those hours (taking 3 decimals only) are, therefore, for 10 hours —·027 and for 16 hours +·041. Dividing each of these by the range, we have —0·40 for the 10-hour factor, and +0·60 for the 16-hour factor. These are constant values for that place and the month in question.

On the 8th July the reduced readings of the barometer at 10 hours

and 16 hours were 27·721 and 27·609. Their difference, or the range for that day, is 0·112. Multiplying this by the factors above determined, we have —·045 as the correction for the 10-hour reading and + ·067 for the 16-hour reading. Applying these to the readings, we obtain—

10-h. reading .	27·721	16-h. reading .	27·609
Correction . .	—·045	Correction . .	+·067
Mean of day .	27·676	Mean of day .	27·676

which is the adopted value: or we may take the *mean* of the two factors as the constant factor for the *mean* of the observations made at the two hours at the time and place specified, and proceed to apply a correction to the *mean* of the two readings, thus:—

10-h. factor . .	—0·40	10-h. reading .	27·721
16-h. „ . .	+0·60	16-h. „ . .	27·609
Mean . .	+0·10	Mean . .	27·665
Range . .	0·112	Correction . .	+0·011
Correction . .	+0·011	Corrected mean .	27·676

The greater the number of readings to which this process is applied, the smaller is the probable error of the result, provided the intervals between the readings are not too small.

139. Factors for temperature.—The readings of temperature, ordinarily recorded, are the maximum and minimum, the 10-hour and 16-hour readings. The maximum and minimum readings are used to determine the range, and the mean of the minimum, 10-hour, and 16-hour readings is corrected by a mean factor. At many stations, in certain months of the year, the maximum is so nearly the same as the 16-hour reading, and occurs so nearly at the same time, that to include it would give undue weight to the afternoon temperature. Let the mean factor for the three readings be +·05, and let the readings of the maximum, minimum, 10-hour and 16-hour be respectively 89°, 72°·5, 83°·5 and 86°. Then proceed as follows:—

Maximum . . .	89·0	Minimum . .	72·5
Minimum . . .	72·5	10-h. reading . .	83·5
		16-h. reading . .	86·0
Range . . .	16·5		
Factor . . .	+·05	Mean . . .	80·7
		Correction . .	+0·8
Correction . .	+0·8		
		Corrected mean .	81·5

140. Factors for the wet-bulb thermometers.—To obtain the mean of the wet-bulb readings, proceed in the same manner as for temperature, with this difference: that, instead of deducing the range from the difference of the maximum and minimum thermometers, the difference of the 16-hour and minimum readings are taken, thus—

16-h. reading	66·6	Minimum	58·0
Minimum	58·0	10-h. reading	71·4
		16-h. reading	66·6
Range	8·6		
Factor	+·08	Mean	65·3
		Correction	+0·7
Correction	+0·7		
		Corrected mean	66·0

In all cases, the factors are, of course, computed originally from mean average readings, homologous with those to which they are to be applied.

141. Computation of mean vapour tension, humidity, &c.—Although not theoretically accurate, an approximate mean diurnal value of these elements, when the range is not very great, may be deduced from the corrected daily means of the dry and wet bulb temperatures, using these means as arguments, and taking the corresponding values out of the table used for the individual observations.

142. Determination of factors.—There are already on record the diurnal curves of pressure for Calcutta, Madras, Bombay, Lucknow, Trevandrum, Dodabetta and Simla, and those of Házáribágh, Patna, Goalpára, and some other stations will shortly be published. Hourly observations are now taken at several other stations in various parts of India, and eventually, from one or other of these, factors may be deduced which will be applicable to any station in India. Some special knowledge and judgment are required to determine which of these is to be selected in each case.

In general, the proper factors for a station will be furnished by the Meteorological office.

143. Monthly and annual mean.—The above description has reference chiefly to the computation of diurnal mean values. It is not often that any such expedients need be resorted to for obtaining annual or monthly means; although, *mutandis mutatis*, a similar course may be followed in their case, if necessary. The monthly mean is the arithmetical mean of all the days in the month, and the annual mean that of all the days in the year. Less accurately, the annual mean is obtained by taking the mean of all the monthly means. This is, indeed, the method

commonly practised; but it is not rigorously accurate, since it assigns to February, with 28 days, an equal importance with January and other months of 31 days each.

144. Mean wind direction.—By this term is to be understood, strictly, the resultant of all the wind movements during the hour, day, month or year; that is to say, the direction and distance to which a particle of air has moved during the period; or rather would have moved, supposing that, at each instant of time, it had the same motion as the air acting on the wind-vane and anemometer. All these movements combined would, in general, give a very circuitous course, but the resultant is the straight line that joins the beginning and end of the path. It can be ascertained, with a near approach to accuracy, only by reducing the trace of an anemograph, such as Beckley's: but, wherever, as in the interior of India, the winds are not very variable, a rough, but useful, generalization may be obtained by tabulating the number of observations under each point of the compass, and deducing the resultant by means of Lambert's formula, in the following manner. Assigning to each wind point its angular value, counted from north through east to south and west, we have—

N.	= 0°	S.	= 180°
N. N. E.	= 22° 30′	S. S. W.	= 202° 30′
N. E.	= 45°	S. W.	= 225°
E. N. E.	= 67° 30′	W. S. W.	= 247° 30′
E.	= 90°	W.	= 270°
E. S. E.	= 112° 30′	W. N. W.	= 292° 30′
S. E.	= 135°	N. W.	= 305°
S. S. E.	= 157° 30′	N. N. W.	= 327° 30′

From a table of natural sines and cosines (or their logarithms,) take out the values of the sines and cosines of each wind point observed, and multiply each by the number of observations recorded under that point. Add together the several products of the sines and the cosines separately; having due regard to their algebraical signs, since + sines are east and —sines west, + cosines north, and — cosines south components. The sum of the sines divided by the sum of the cosines gives the tangent of the resultant direction; and the square root of the sum of their squares, divided by the whole number of observations and multiplied by 100, gives the excess percentage of observations in the direction of the resultant.

When an anemogram which shews the distance travelled by the wind in each direction is thus treated, the proceeding is modified. The trace is first measured off and tabulated under as many points as may be found convenient, the number of *miles* recorded in each direction being entered under its proper point. The calculation is then proceeded with as above

described, the total number of miles under each point being used as the multiplier, instead of the number of observations, and the square root of the sum of the squares of the summed sines and cosines gives at once the number of miles travelled in the direction of the resultant.

145. Bessel's interpolation formula.—This formula is now so extensively used in the reduction of meteorological observations, that any description of methods of reduction would be very imperfect without some account of its use and application. Suppose the object be to ascertain the most probable course and law of the diurnal oscillation of the barometer at a given station, and let a series of hourly observations be undertaken for that purpose. Since this oscillation, which is regularly recurrent, is combined with a number of changes of pressure which are irregular and non-periodic, a single day's readings when projected in a curve will give some such irregular figure as that in the accompanying woodcut. If the observations are repeated for several days in succession, the greater irregularities of the individual curves will tend to neutralize each other, and something more like an evenly regular curve will begin to disclose itself in the figure which is given by the average of the whole. But completely to eliminate all irregularities would require the observations to be carried on for some years, and in certain cases very much longer. Now Bessel's formula affords the means of ascertaining the probable form of the curve from a comparatively moderate amount of data, and enables us to eliminate at once all such minor irregularities as affect small portions of the curve only.

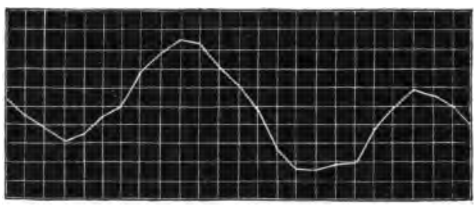

Figure 15. [a]Curve of hourly barometric observations.

The fundamental principle of the method is this,—that the march of every phenomenon that goes through a regular cycle in a given fixed period, after which all its phases are repeated again and again in the same order and with the same magnitude, may be conceived as made up of elements, of which one is constant; another, during the cycle, goes *once* through all the variations of magnitude, positive and negative, represented by the sines of the regularly increasing arc of a circle,

[a] This curve is plotted from an actual register at Jubbulpore, and is more regular than usual.

of which the maximum value of that element is the radius; another of different magnitude goes *twice* through a similar revolution; a third three times, and so on. And thus, if we determine from observation the maximum numerical value of each of these elements, and also that phase of its revolution, at which it is at some fixed moment, (for instance, at midnight in the case of the diurnal cycle of a phenomenon), we can compute the value of the whole phenomenon at any other instant in the cycle, counting the time from midnight, at the rate of 15° of arc for each hour for the first periodical element, 30° for the second, 45° for the third, and so on; and then taking the sum of the whole and of the constant element.

Thus, then, let M represent the constant element, U', U'', U''' the maximum values of the first, second and third periodical elements, and u', u'', u''' the arcs which determine the phases of the several elements at midnight, measured from the zero point of arcs and sines in each of the corresponding circles. Then, if x be the value of the whole phenomenon at midnight—

$$x = M + U' \sin. u' + U'' \sin. u'' + U''' \sin. u''', \&c.$$

And if x' is the value at any epoch n hours later, (n being any value whatever, integral or fractional) counted from midnight—

$$(1). \quad x' = M + U' \sin. (n15^\circ + u') + U'' \sin. (n30^\circ + u'') + U''' \sin. (n\,45^\circ + u'''), \&c.$$

The formula will contain as many terms as there are elements computed. The number of these may be varied at the judgment of the computer; generally, it is found that, after the first three or four terms, the co-efficients become so small that they may be neglected without appreciably affecting the result.

The probable value of the constant co-efficients has been determined by Bessel, by the method of least squares; and the demonstration will be found in the original paper in Schuhmacher's *Astronomische Nachrichten*, and in the translation published by Mr. R. H. Scott as Appendix IV to the Quarterly Weather Reports of the Meteorological Office, London, for 1870; also in the Introduction to Schmidt's Meteorologie. The practical application is as follows;—

Let the subject of investigation be the diurnal variation of temperature; and suppose that, having recorded hourly readings on a sufficient number of days to eliminate all the greater irregularities, we obtain as the means, for each consecutive hour, counted from midnight, the values s_0, s_1, s_2, s_3, s_4, *&c.* . . . . s_{23}. Adding the whole together and taking their mean, we obtain the constant term *M*, which is the mean temperature of the day.

Then proceed to compute out the values of $U' \, sin. \, u'$, $U' \, cos. \, u'$, &c., by the following formulæ:—

$$U' \, sin. \, u' = {}^1/_{12} \, [s_0 - s_{12} + (s_1 - s_{11} - s_{13} + s_{23}) \, cos. \, 15^\circ + (s_2 - s_{10} - s_{14} + s_{22}) \, cos. \, 30^\circ + (s_3 - s_9 - s_{15} + s_{21}) \, cos. \, 45^\circ + (s_4 - s_8 - s_{16} + s_{20}) \, cos. \, 60^\circ + (s_5 - s_7 - s_{17} + s_{19}) \, cos. \, 75^\circ].$$

$$U' \, cos. \, u' = {}^1/_{12} \, [(s_1 + s_{11} - s_{13} - s_{23}) \, sin. \, 15^\circ + (s_2 + s_{10} - s_{14} - s_{22}) \, sin. \, 30^\circ + (s_3 + s_9 - s_{15} - s_{21}) \, sin. \, 45^\circ + (s_4 + s_8 - s_{16} - s_{20}) \, sin. \, 60^\circ + (s_5 + s_7 - s_{17} - s_{19}) \, sin. \, 75^\circ + s_6 - s_{18}].$$

whence $\dfrac{U' \, sin. \, u'}{U' \, cos. \, u'} = tang. \, u'$

The angle or arc u' corresponding to the value $tang. \, u'$ can be looked out in any table of trigonometrical constants, and, taking $sin. \, u'$ from the same table, $\dfrac{U' \, sin. \, u'}{sin. \, u'} = U'$. The co-efficients of the next term are found by the following formulæ:—

$$U'' \, sin. \, u'' = {}^1/_{12} \, [s_0 - s_6 + s_{12} - s_{18} + (s_1 - s_5 - s_7 + s_{11} + s_{13} - s_{17} - s_{19} + s_{23}) \, cos. \, 30^\circ + (s_2 - s_4 - s_8 + s_{10} + s_{14} - s_{16} - s_{20} + s_{22}) \, cos. \, 60^\circ].$$

$$U'' \, cos. \, u'' = {}^1/_{12} \, [(s_1 + s_5 - s_7 - s_{11} + s_{13} + s_{17} - s_{19} - s_{23}) \, sin. \, 30^\circ + (s_2 + s_4 - s_8 - s_{10} + s_{14} + s_{16} - s_{20} - s_{22}) \, sin. \, 60^\circ + s_3 - s_9 + s_{15} - s_{21}]$$

from which, as before, we obtain—

$$\frac{U'' \, sin. \, u''}{U'' \, cos. \, u''} = tang. \, u'' \text{ and } \frac{U'' \, sin. \, u''}{sin. \, u''} = U''.$$

The values of U''' and u''' are given by the formulæ—

$$U''' \, sin. \, \mu''' = {}^1/_{12} \, [s_0 - s_4 + s_8 - s_{12} + s_{16} - s_{20} + (s_1 - s_3 - s_5 + s_7 + s_9 - s_{11} - s_{13} + s_{15} + s_{17} - s_{19} - s_{21} + s_{23}) \, cos. \, 45^\circ].$$

$$U''' \, cos. \, u''' = {}^1/_{12} \, [(s_1 + s_3 - s_5 - s_7 + s_9 + s_{11} - s_{13} - s_{15} + s_{17} + s_{19} - s_{21} - s_{23}) \, sin. \, 45^\circ + s_2 - s_6 + s_{10} - s_{14} + s_{18} - s_{22}].$$

from which U''' and u''' are found as before; and if a fourth term be required—

$$U'''' \, sin. \, \mu'''' = {}^1/_{12} \, [s_0 - s_3 + s_6 - s_9 + s_{12} - s_{15} + s_{18} - s_{21} + (s_1 - s_2 - s_4 + s_5 + s_7 - s_8 - s_{10} + s_{11} + s_{13} - s_{14} - s_{16} + s_{17} + s_{19} - s_{20} - s_{22} + s_{23}) \, cos. \, 60^\circ].$$

$$U'''' \, cos. \, u'''' = {}^1/_{12} \, (s_1 + s_2 - s_4 - s_5 + s_7 + s_8 - s_{10} - s_{11} + s_{13} + s_{14} - s_{16} - s_{17} + s_{19} + s_{20} - s_{22} - s_{23}) \, sin. \, 60^\circ].$$

From a careful study of the above, the reader will readily gather the principle which will enable him to construct formulæ for any required number of terms. In applying the formula to other cases, such as the computation of the annual curve from 12 monthly means, or the variation of the wind co-ordinates from observations tabulated to eight or sixteen points, or, to speak generally, from any number m sets of observations, which divide the whole cycle into m equal parts, it is

to be observed that the fractional co-efficient represented above by $\frac{1}{12}$ is always $\frac{2}{m}$; therefore $\frac{1}{6}$ for 12 sets; and $\frac{1}{4}$ for 8; and that the arcs which are 15° and multiples of 15° in the above formulæ are replaced by $\frac{360°}{m}$ and its multiples.

The values of the constant co-efficients in formula (1) having been found, those of the whole phenomenon may then be calculated by the formula for each hour (or other interval) in succession, by giving to n its consecutive values 1, 2, 3, &c., or any others that may be desired.

The following example will serve as an exercise to familiarize the student with the use of the formula.

The hourly and six-hourly observations of temperature at Yarkand in the spring months March, April and May, after some minor corrections, gave the following average values :—

Hour.	Temp.	Hour.	Temp.	Hour.	Temp.	Hour.	Temp.
Mid. ...	54·6	6 ...	49·6	Noon ...	71·8	18 ...	65·3
1 ...	53·1	7 ...	53·6	13 ...	72·2	19 ...	62·2
2 ...	51·7	8 ...	58·3	14 ...	72·7	20 ...	60·1
3 ...	50·3	9 ...	63·3	15 ...	72·3	21 ...	58·7
4 ...	49·4	10 ...	67·5	16 ...	71·4	22 ...	57·3
5 ...	48·9	11 ...	69·5	17 ...	68·6	23 ...	55·9

The mean of the whole, $M = 60·76$

$$\begin{array}{lr}
54·6 - 71·8 = & -17·2 \\
(53·1 - 69·5 - 72·2 + 55·9)\ \cos.\ 15° = & -31·59 \\
(51·7 - 67·5 - 72·7 + 57·3)\ \cos.\ 30° = & -27·02 \\
(50·3 - 63·3 - 72·3 + 58·7)\ \cos.\ 45° = & -18·81 \\
(49·4 - 58·3 - 71·4 + 60·1)\ \cos.\ 60° = & -10·10 \\
(48·9 - 53·6 - 68·6 + 62·2)\ \cos.\ 75° = & -2·87 \\
\hline
12\,) & -107·59 \\
\hline
U'\ \sin.\ u' = & -8·966
\end{array}$$

$$\begin{array}{lr}
(53·1 + 69·5 - 72·2 - 55·9)\ \sin.\ 15° = & -1·52 \\
(51·7 + 67·5 - 72·7 - 57·3)\ \sin.\ 30° = & -5·40 \\
(50·3 + 63·3 - 72·3 - 58·7)\ \sin.\ 45° = & -12·30 \\
(49·4 + 58·3 - 71·4 - 60·1)\ \sin.\ 60° = & -20·61 \\
(48·9 + 53·6 - 68·6 - 62·2)\ \sin.\ 75° = & -27·34 \\
49·6 - 65·3 = & -15·70 \\
\hline
12\,) & -82·87 \\
\hline
U'\ \cos.\ u' = & -6·906
\end{array}$$

$$\frac{-8\cdot966}{-6\cdot906} = 1\cdot2994 = \textit{tang.}\ 232^\circ\ 25'$$

$$\frac{-8\cdot966}{\textit{sin.}\ 232^\circ\ 25'} = 11\cdot32.$$

$$\therefore \quad U' = 11\cdot32\ u' = 232^\circ\ 25'.$$

Computing U'' and u'', U''' and u''', U'''' and u'''' in a similar manner by their respective formulæ, we obtain—

$$U'' = 2\cdot643 \text{ and } u'' = 84^\circ\ 21'$$
$$U''' = 0\cdot911 \quad ,, \quad u''' = 36^\circ\ 45'$$
$$U'''' = 0\cdot567 \quad ,, \quad u'''' = 234^\circ\ 11'$$

and substituting these values in (1)—

$$x' = 60\cdot76 + 11\cdot32\ \textit{sin.}\ (n\ 15^\circ + 232^\circ\ 25') + 2\cdot64\ \textit{sin.}\ (n\ 30^\circ + 84^\circ\ 21') + 0\cdot91\ \textit{sin.}\ (n\ 45^\circ + 36^\circ\ 45') + 0\cdot57\ \textit{sin.}\ (n\ 60^\circ + 234^\circ\ 11')$$

In the next place we proceed to compute the probable hourly values of the temperature. By the formula for midnight we have simply—

$$x_0 = M + U'\ \textit{sin.}\ u' + U''\ \textit{sin.}\ u'' + U'''\ \textit{sin.}\ u''' + U''''\ \textit{sin.}\ u''''$$
$$= 60\cdot76 - 8\cdot97 + 2\cdot63 + \cdot54 - \cdot46 = 54\cdot51.$$

For 1 A.M.—

$$n = 1$$

$$\therefore x_1 = 60\cdot76 + 11\cdot32\ \textit{sin.}\ (15^\circ + 232^\circ\ 25') + 2\cdot64\ \textit{sin.}\ (30^\circ + 84^\circ 21') + 0\cdot91\ \textit{sin.}\ (45^\circ + 36^\circ\ 45') + 0\cdot57\ \textit{sin.}\ (60^\circ + 234^\circ\ 11')$$

which, being calculated out, gives—

$$60\cdot76 - 7\cdot66 = 53\cdot10.$$

For 2 A.M.—

$$n = 2$$

$$\therefore x_2 = 60\cdot76 + 11\cdot32\ \textit{sin.}\ (30^\circ + 232^\circ\ 25') + 2\cdot64\ \textit{sin.}\ (60^\circ + 84^\circ 21') + 0\cdot91\ \textit{sin.}\ (90^\circ + 36^\circ\ 45') + 0\cdot57\ \textit{sin.}\ (120^\circ + 234^\circ\ 11')$$

which gives—

$$x_2 = 60\cdot76 - 9\cdot01 = 51\cdot75.$$

Having thus computed all the values x_3, x_4, &c., up to x_{23}, let us arrange them in parallel columns with the original means, and take the differences in a third column—

Hour.	s.	x.	Difference.	Hour.	s.	x.	Difference.
Mid.	54·6	54·51	— 0·09	6	49·6	50·04	+ 0·44
1	53·1	53·10	0	7	53·6	53·36	— 0·24
2	51·7	51·75	+ 0·05	8	58·3	58·22	— 0·08
3	50·3	50·39	+ 0·09	9	63·3	63·32	+ 0·02
4	49·4	49·18	— 0·22	10	67·5	67·42	— 0·08
5	48·9	48·78	— 0·12	11	69·5	69·98	+ 0·48

Hour.	*s.*	*x.*	Difference.	Hour.	*s.*	*x.*	Difference.
Noon.	71·8	71·35	−0·45	18	65·3	65.30	0
13	72·2	72·20	0	19	62·2	62·30	+ 0·10
14	72·7	72·73	+ 0·03	20	60·1	60·10	0
15	72·3	72·57	+ 0·27	21	58·7	58·60	−0·10
16	71·4	71·20	−0·20	22	57·3	57·32	+ 0·02
17	68·6	68·58	−0·02	23	55·9	55·96	+ 0·06

These differences or errors are not larger than might be expected, regard being had to the comparatively moderate number of the observations from which the means are derived; and, moreover, they present that irregularity which characterizes them as probable errors. We may, therefore, consider the computed values x_0, x_1, &c., as the most probable temperatures.

As here described, the calculation may seem somewhat tedious, but in practice it is very quickly carried out with the help of logarithms. After a little practice, a fairly good computer will calculate the whole in an hour or less.

146. Instants of maxima and minima.—By the help of this formula the instants at which any phenomenon attains its maximum and minimum values, and these values themselves may be ascertained with great accuracy. It follows from algebraical reasoning, that x will have either a maximum or a minimum value, when the value of n is such that

$$(2)\quad U'\ cos.\ (n\ 15^\circ + u') + 2\ U''\ cos.\ (n\ 30^\circ + u'') + = 0$$
$$3\,U'''\ cos.\ (n\ 45^\circ + u''')\ \&c.$$

Dr. Jelinek has given the following method of determining this value very expeditiously, when the values of x_0, x_1, x_2, &c., have been calculated out. These computed values shew very nearly when a phenomenon reaches its maximum or minimum; for instance, in the above example, the minimum temperature is clearly a little before 5h. and the maximum a little after 14h. Let us take out from the table the values at 5h. and 14h., and those of the even hours before and after, and thence obtain the first and second differences Δ_1 Δ_2—

	Minimum.			*Maximum.*		
	49·18	48·78	50·04	72·20	72·73	72·57
Δ_1	−0·40		+1·26	+0·53		−0·16
Δ_2		+1·66			−0·69	

Now, by the method of differences, if we start with the value at the middle hour of the triad, *i. e.*, the even hour nearest to minimum (or maximum), the value at any *later* instant t (t being less than 1 hour) will be found by the formula—

$$A + t\Delta_1' + \frac{t(t-1)}{2}\Delta_2 + \frac{(t+1)t(t-1)}{2\cdot 3}\Delta_3' + \&c.,$$

in which A is the initial value, Δ_1' the first subsequent difference, Δ_2 the second coincident difference, &c., at the same hour. The value of this equation will reach a minimum (or maximum) value when its differential coefficient becomes zero, that is, when

$$(3)\quad \Delta_1' + (t-\tfrac{1}{2})\Delta_2 + \&c., = 0$$

Now, taking the first and second, and neglecting the higher differences, we obtain from this equation an approximate value of t. Let us call this value t';

$$t' = \tfrac{1}{2} - \frac{\Delta_1'}{\Delta_2}$$

and substituting for Δ_1' and Δ_2 the values, found above for the hour nearest the minimum—

$$t' = 0{\cdot}5 - \frac{1{\cdot}26}{1{\cdot}66} = -0{\cdot}26\text{hour} = 15\text{min. } 36\text{sec. earlier than 5h.};$$

and with the values for that nearest the maximum—

$$t' = 0{\cdot}5 - \left(\frac{-0{\cdot}16}{-0{\cdot}69}\right) = 0{\cdot}27\text{hour} = 16\text{min. } 12\text{sec. later than 16h.}$$

By this first approximation the minimum temperature occurs at 4 hours 44 minutes, and the maximum at 14 hours 16 minutes.

In order to obtain a second and closer approximation for the minimum (the maximum may be treated in like manner), convert 4 hours 44min. into degrees and min. of arc; substitute it and its multiples for $n15°$ and its multiples in equation (2), and calculate out the numerical value of the equation. It will not be 0, since t' is not exactly the true moment of minimum. Instead of this, we find—

$$11{\cdot}32\cos(71°6'+232°25') + 5{\cdot}286\cos(142°12'+84°21') + \quad = -0{\cdot}4285$$
$$2{\cdot}733\cos(213°18'+36°45') + 2{\cdot}268\cos(284°24'+234°11')$$

Let us call this value f. Now the expression in equation (2), if multiplied by $dn\ \sin.1''$ will represent the increment (or decrement) of temperature that ensues in the time that $n15°$ increases by dn seconds of arc. If we assume that this rate of increment remains constant for an hour, then, since $dn = 15° = 54{,}000$ seconds, and $dn\ \sin.1'' = 54{,}000\ \sin.1'' = 0{\cdot}2618$,

$$0{\cdot}2618f = -(0{\cdot}4285 \times 0{\cdot}2618)$$

is the change of temperature, which, on this assumption, would take place in an hour, if it continued at the same rate of change as at the instant t' found by the first approximation. The expression—

$$\Delta_1' + (t'-\tfrac{1}{2})\Delta_2 +, \&c.,$$

has the same signification; and therefore

$$\Delta_1' + (t' - \tfrac{1}{2})\,\Delta_2 + \&c. = 0{\cdot}2618f$$
$$t' - \frac{0{\cdot}2618f}{\Delta_2} = \tfrac{1}{2} - \frac{\Delta_1'}{\Delta^2}, \&c., = t$$

wherein t is the second approximation. Hence—

$$\frac{0{\cdot}2618f}{\Delta_2} = \frac{(0{\cdot}2618 \times -0{\cdot}4285)}{1{\cdot}66} = -\ {\cdot}0676$$

is the correction to be deducted from t' (with due regard to the algebraical sign) in order to obtain t the second approximation—

$$-0{\cdot}26-(-{\cdot}0676) = -\ 0{\cdot}1924 = -11\text{min. }33\text{sec.}$$

and, neglecting seconds, the instant of minimum temperature is thus found to be 5h. *less* 12min. = 4h. 48min. The process may, of course, be repeated to obtain a third approximation, but there can be no practical object in aiming at greater precision than is already attained by the second approximation as above.

Having ascertained with sufficient exactness the instants of maximum or minimum by the above methods, the value of the maximum and minimum, and consequently the range of the variation, may be easily found: convert the time of their occurrence into degrees of arc, and substitute this value for n 15°, &c., in equation (1), page 72. The resulting values will be those of the maximum and minimum, and their difference will be the range.

REGISTRATION.

147. Forms.—Specimens of the principal forms of register in use in the Indian Meteorological Department are appended. Those marked A. and B. are for general use at all stations at which observations are recorded regularly at 10*h.* and 16*h.*, the rain-gauge and maximum thermometers being read also at 18*h.* Those marked E. and F. are for hourly observations.

148. Form B.—This is for recording the readings as made, *without any correction or reduction.* The name of the station is to be entered at the top of the form, and the distinguishing numbers of the several instruments in the first column after their names. The entries for the first and fifteenth, (in February the fourteenth), day of the month should begin a new form; and since each form contains the register of eight days, four forms will be required for each month, the columns for one or two days (in February two or three days), being left unfilled in the last form. The name of the month, together with the ordinal number of the day, is to be entered in the first blank space at the top: on the remaining days the ordinal number alone will suffice. The instruments to be read at the hours directed in §§ 128 and 129.

149. Form A.—This is for the reduced and corrected readings, the half-monthly and monthly means, &c.; and each form is intended to receive the register for one month. The name of the station, that of the month, the latitude and longitude, the elevation of the barometer cistern above sea-level and the distance of the station in a direct line from the sea, are to be entered at the top of each form in a neat *round hand.* The smaller entries in small hand, *viz.*:—

1st.—The place in which the thermometers are exposed, as "thatched shed open all round," or "louvred shed of plank work," or "north verandah," &c., and the height of the frame or cage above the ground.

2nd.—The mode in which the hygrometric elements have been computed, such as "Met. Dep. Tables IV, V and XII," "Apjohn's formula," "August's formula," "Glaisher's tables," &c.

3rd.—The source from which the hour corrections have been obtained, thus, "range factors from local hourly observations," "range factors from Calcutta hourly observations," "range factors from local six-hourly observations," &c.

4th.—The height of the solar radiation thermometer above the ground.

5th.—That of the grass radiation thermometer. And after the word "ground" should be added such words as "over thick green grass," "over dry grass," "over thinly-growing tufted grass," "over bare ground," "over black woollen cloth," &c. In some cases this entry will vary with the time of year.

6th.—The height of the *mouth* of the rain-gauge above the general ground level.

7th.—A brief description of the position of the anemometer, such as "a post fixed in the ground," "post three feet high on north-east corner of terraced roof," "post 5 feet high on ridge of roof of dispensary, &c." Also in all cases the height of the anemometer cups above the ground.

In the first column the days of the week to be designated by their initials. For that of Sunday the sun symbol ⊙ may be substituted. In February the first half month should close on the 14th, and the figures of the second half should be altered.

Columns 1 *to* 6.—Enter, before the word 'barometer' at the top, an abbreviated description of the kind of instrument in use, such as "Marine K. P." (Marine Kew Principle), "Mountain Fort." (Mountain, Fortin's principle), "Stand. Fort." (Standard, Fortin's principle). Also the distinguishing number, and the initials or first syllable of the maker's name as "946 Cas." (Casella), "734 N. and Z." (Negretti and Zambra), &c. In columns 2 and 3 enter the barometric readings at 10h. and 16h., corrected and reduced (§§ 12, 14), in column 1 their difference, in column 4 the correction for the day (§ 138), and in column 5 the corrected mean. In column 6 the mean corrected to sea-level (§ 15).

Columns 7 *to* 14.—Enter, at the top of the column, the distinguishing numbers of the maximum, minimum and the dry bulb of the hygrometer. In columns 7 and 9 the readings of the minimum and maximum thermometers corrected for index error, and in column 8 their difference. In columns 10 and 11 the corrected readings of the dry-bulb thermometer. In column 12, the correction obtained by multiplying the proper factor into the figures in column 8 (§ 139), and in column 13 the mean of the figures, in columns 7, 10 and 11 with the addition of the correction. Lastly, in column 14, the sea-level equivalent of the mean temperature, which is obtained by adding a constant correction to the values in column 13. In the case of hill stations column 14 is to be left blank.

Columns 15 *to* 19.—As the above, with the variations in the method of deducing the correction for hours, for the wet-bulb thermometers, described in § 140.

Columns 20 *to* 23.—The entries in column 20 are the vapour tensions computed or taken out of the proper table [§ 70] from the readings of the dry and wet bulb minimum thermometers in columns 7 and 15; in columns 21 and 22 from the readings of the hygrometer in columns 10, 11, 16 and 17; and in column 23 from the means in columns 13 and 19.

Columns 24 *to* 27.—As the above, from the proper humidity tables (§ 73).

Columns 28 *to* 31.—From the vapour tensions in the corresponding columns 20 to 23, and with the temperatures in columns 7, 10, 11 and 13, the weight of vapour computed from Table XII.

Columns 32 *and* 33.—In column 32, the corrected reading of the solar radiation thermometer, and in column 33 the difference of this and the corrected maximum shade temperature in column 9.

Columns 34 *and* 35.—The corrected reading of the grass minimum thermometer and the difference of this and the reading of the minimum shade thermometer in column 7.

Columns 36 *to* 38.—In column 36 the difference of the anemometer reading at 10h. of the day of record and at 16h. of the previous day. In 37 that of the 10h. and 16h. readings, and in 38 the sum of these two entries.

Columns 39 *and* 40.—The wind directions observed at 10h. and 16h. according to 16 points, indicated by the letters in § 83: care must be taken to enter '*c.*' for calm, when the anemometer is not moving at the time of observation.

Column 41.—The rain measured at 18h.

Columns 42 *to* 44.—The cloud proportion estimated at 10h. and 16h. (§ 99), and in column 44 the mean of the two. If there is no cloud, a zero '0' is to be entered; if no observation has been made, a '?'.

Columns 45 *to* 47.—Cloud symbols, Beaufort's initials and Vienna symbols, for which see § 112; noting that these cloud symbols are to be entered in printing capitals, thus C, except when double, as Ck. The Beaufort's initials in small italics. The hours at, or between, which any phenomenon occurs should be entered thus T ↯ 13h.—16h., ⌓ 6h. Such words as 'cool,' 'pleasant,' 'sultry,' &c., may well express the feelings of the observer and may be interesting to his friends; but they are not of importance in a meteorological register, and may be omitted with advantage.

Sums and means.—The sums and means of all the columns are to be entered at the foot of the form, except in the case of the wind direction, rain, columns 39, 40, 41 and weather symbols, &c., in columns 45 to 47. In the case of the wind direction, the space may be left blank, or the resultant computed by Lambert's formula (§ 144), may be inserted; in the case of the second, the sum only is required, and in that of the third the only summary possible would be a simple enumeration of the several symbols. This space, therefore, may be left blank. In taking the means of cloud proportion, the sum of each column is to be divided by the whole number of days in the month, notwithstanding that '0' may be entered on several days.

Maximum and minimum.—It is convenient when a month's register has been completed, to mark the highest and lowest value of each kind of phenomenon, by underscoring the entry with red ink.

150. Forms E and F.—These correspond respectively to Forms B and A above described, but are intended for hourly readings. They require no special description. The last column on Form F. is intended for the initials of the observers who take the several observations.

151. Neatness.—*A meteorological register should be kept with the same neatness as a merchant's ledger. Slovenliness and indistinctness in the entries are a tolerably sure indication that the work recorded has been of the same character.*

RULES FOR OBSERVERS AT GOVERNMENT OBSERVATORIES IN INDIA.

GENERAL.

1. *Punctuality.*—Take observations at the appointed hours [§§ 128, 129, 130] according to local mean time, not railway time. Keep the clock accurately regulated and begin to take the observations two minutes before the hour. Be punctual and accurate [§ 131].

2. In storms observe all instruments as frequently as possible, [§ 133].

3. Never allow of any break or discontinuity in the register, if it can *possibly* be avoided; specially in the raingauge observations. But if any such break is unavoidable, make no attempt to fill it by interpolation.

4. *Cleanliness.*—Every instrument is to be kept scrupulously clean. The feather of a quill or a soft brush may be used to dust the more delicate instruments; a soft cloth, slightly damped, to clean the glass of the larger instruments.

5. *Change of instruments.*—Every instrument differs from others of the same kind in *some* particulars: each has errors peculiar to it, and requires its own special corrections [§§ 11, 12, 26, 27, 51, 91]. If, therefore, any instrument be changed, *e. g.*, one thermometer substituted for another, report the fact by letter to the Meteorological Reporter, giving the number and description of the substituted instrument, and of that replaced, and enter the same at the foot of the register form, with the hour and date at which the substituted instrument was first observed.

6. *Change of position.*—The place and position of an instrument are *never* to be changed, unless the change is *absolutely necessary*. In the case of most instruments, the barometer and sun thermometer more especially, any change of place introduces a permanent change in the average readings of the instrument [§§ 15, 16]. If unavoidable, the Meteorological Reporter *is to be apprized of the proposed change beforehand;* and, when effected, the date and other particulars are to be reported to him, and also entered on the register.

BAROMETER.

7. *Unpacking and suspending.*—Take the barometer out of its case, cistern upwards. If on Fortin's principle, unscrew the milled headed screw at the bottom of the cistern [§ 4] one or two turns, then invert the barometer, *slowly* and *gently*, and suspend it to a strong nail or spike, at such a height that the 31-inch mark of the scale is about on the level of the eye of the observer.

8. *Verticality.*—When the barometer is suspended and before any reading from it is taken, ascertain that it is truly vertical by means of a plumb line, viewed both in front and from the side [§ 2].

9. *Place for barometer.*—The barometer must, as far as possible, be protected from all changes of temperature. A thermometer shed is the worst possible place for it. It should be in an inner room, where there is a good side light [§ 17].

10. The sun must never shine on it. The light should be from the side, not from the back or front, of the instrument. The 31-inch mark should be at the level of the observer's eye when standing upright. A sheet of white paper, or other white surface, well illuminated, should be behind the cistern and the top of the column [§ 17].

11. *Level.*—The level of the mercury surface of the cistern, above or below the nearest bench mark, is to be ascertained by spirit levelling. The readings of a barometer, the exact elevation of which is unknown, are of little use [§§ 15, 16].

12. The bench mark should be, if possible, one fixed by the spirit-levelling parties of the Great Trigonometrical Survey. Failing this, it may be one the height of which above sea level has been ascertained by the irrigation officers, railway engineers, or trigonometrically by the Great Trigonometrical Survey [§ 16].

13. At stations on the sea coast, the level may be referred to the mean half-tide level.

14. *Order of observation.*—First read the attached thermometer, and note the reading. Then regulate the cistern level [§ 4]. Next, adjust the vernier [§ 9], and take the reading, and finally look again at the attached thermometer to verify the first reading.

15. The vernier is to be read to the nearest thousandth of an inch.

16. *Night readings.*—Never place a lamp or candle near the barometer, but at a distance of not less than one foot.

17. Throw the light *on the paper* behind the cistern and column, while adjusting the cistern level and vernier.

18. *Injuries and accidents.*—Sometimes, on unpacking a barometer after a journey, a little mercury is found to have leaked from the cistern. But the barometer *may* be in good order. To ascertain this, test the vacuum cautiously [§ 18], then regulate the cistern level [§ 4]. If the vacuum is good, and the mercury touches the ivory stud, the instrument is probably in good order.

19. See that the cistern bottom (not the regulating screw) is screwed well home, and *never unscrew it.* Leaking from the cistern is frequently owing to the cistern bottom being loose.

20. Drops of mercury condensed in the Torricellian vacuum above the column, are of no importance, and do not affect the reading.

21. If the vacuum be imperfect, or any part of the barometer be broken, return the instrument for repair.

22. *Repacking.*—Always send barometers packed on a bamboo dooly, carried by two men [§ 19].

23. Detach the barometer from its suspension, screw up the mercury to the top of the cistern, then invert the instrument cautiously, and give the cistern screw another turn, but leave an air space about equal to the bowl of a teaspoon. Place in the case, cistern upwards, and take care that in carriage it is kept in this position.

THERMOMETERS AND HYGROMETERS.

24. *Suspension.*—Suspend the thermometers as shewn in the diagram, Plate I, so that the bulbs may be between 3 feet 9 inches and 4 feet 6 inches above the ground, and the wet and dry bulbs as far from each other as the frame will admit of. Expose them under a shed, of the form and dimensions shown in Plate I.

25. Never suspend thermometers for meteorological purposes in an office or dwelling-room. If no shed is available, suspend them on a frame standing (not against a wall) in a verandah having a northern aspect. But in such a position they will not shew the range of temperature [§ 35].

26. They must be protected, not only from direct sunlight, but also, as far as possible, from the radiation of surfaces strongly heated by the sun. But they should be freely exposed to the wind.

27. For the position of radiation thermometers, see §§ 46, 47, 51.

28. *Observations.*—Read thermometers as quickly as possible, taking care that the eye is *exactly* on the level of the top of the column if the thermometer is vertical, and exactly opposite (neither to right nor left of it) if horizontal. The smallest deviation introduces an error: [§ 28].

29. Do not bring the hand or face near the bulb, and do not bring a lamp at night time nearer than can be helped.

30. Read thermometers, by estimation, to the nearest tenth of a degree.

31. Before reading a minimum or other spirit thermometer, *always* examine the tube to see that there are no drops of spirit in the upper parts of the tube and no air bubbles in the spirit column and bulb. Especially look beneath the brass staple that fixes the tube and in the expansion at the top of the stem. If the column is not entire, reject the reading and restore the column *at once,* [§ 43].

32. After writing down the reading of a thermometer, look again at the instrument to check its accuracy.

33. *Wet-bulb thermometers.*—These must be freely exposed to the wind.

34. They must be kept clean, and free from encrustation. The muslin and thread to be washed at least once a week and renewed at least once a month.

35. If possible, use rain-water only, and store it for the purpose. In rainless regions, use distilled water if you can get it. If not, *boil* water well and long, and filter it before using it.

36. The muslin must fit closely to the bulb and not hang in folds. It must be thin and applied in one thickness only. To renew it, cut a piece about one inch square; wet it well, apply it to the bulb and draw it closely over it; tie it with a bundle of 8 or 10 clean and well-washed yarn threads, and cut off the free edges neatly.

37. When the wet bulb is below the freezing point, it must be dipped in water half an hour before the reading is taken, [§ 67].

38. *Radiation thermometers.*—The grass thermometer is especially liable to separation of the column. Always examine it before reading, and rectify it [§ 43] before re-exposing it. See Rule 31. If dew is deposited in the protecting tube, wipe it out with a piece of cotton on a wire.

39. Sun thermometers sometimes have a minute piece of the mercurial column (= 2 or 3 degrees) detached, and difficult to re-unite. In such cases measure the length it subtends in degrees, and add the amount to the reading, until you can get it to re-unite.

40. Sun thermometers on Phillip's principle [§ 39] are liable to lose the air speck which separates the index. In this case the instrument no longer acts as a maximum. This is easily detected, since the column under these circumstances contracts with every fall of temperature.

41. If the glass jacket of a sun thermometer is the least cracked, the instrument must be rejected.

42. Never change the place of exposure of a sun thermometer nor its height above the ground, if it can be avoided. If unavoidable, report the change and date of the removal.

43. Never leave a radiation thermometer exposed to hail. If a thunder storm is imminent, remove it to a place of safety till the storm is over.

44. *In case of accidents.*—If the dry-bulb thermometer be broken, take the readings of the maximum till it can be replaced, resetting it at each observation before taking the reading.

45. If the minimum in air be broken, read the standard *before sunrise* instead.

46. If the ordinary wet bulb be broken, take the *actual* reading of the minimum wet bulb.

47. If the minimum wet bulb be broken, take the reading of the ordinary wet bulb *before sunrise* instead.

RAINGAUGE.

48. *Position.*—Fix the gauge in an open place, as far as possible from trees, houses and other obstructions. It should in no case be within 30 paces of any building or tree [§ 81].

49. Bury the gauge or its stand *firmly* in the ground, leaving the mouth of the funnel one foot above the ground [§ 78].

50. *Hours of observation.*—Read and empty the gauge regularly at 18h.; during heavy rain more frequently, and so often as to incur no risk of loss by its running over. At telegraphing stations read the rain regularly at 10h. and 16h. likewise.

Measuring.—See that the measure-glass is empty before measuring. Place the measure-glass on a large dish, and pour the contents of the receiver into it slowly and carefully, to avoid spilling. The measure holds one inch.[a] If the receiver contain more than one inch, fill the former up to the one-inch mark. Then empty it and refill. Each entire filling represents one inch of rainfall. The last partial filling is read off on the graduation as tenths and hundredths.

52. If the measure of a Symon's gauge be broken, measure the rainfall in an apothecary's glass graduated to fluid ounces, and compute therefrom the rainfall as directed in § 78.

53. If the receiver of a raingauge leak, it may be repaired by an ordinary mechanic; but if the form of the rim of the receiving funnel is altered, if it be not *truly* circular (or *truly* square), the gauge registers falsely and is worse than useless.

---

[a] The measure-glasses of some gauges hold half an inch only. In such cases the words *half inch* must be substituted for *inch* in this rule.

ANEMOMETER AND WIND-VANE.

54. *Choice of site and fixing.*—These instruments are to be fixed on the *highest point* of the house occupied by the observer, if the following conditions are fulfilled:—

(*a*).—If no trees loftier than the house are in the immediate neighbourhood.

(*b*).—If there be no much loftier house within 50 yards.

55. The vane and anemometer cups must not be less than four feet above the highest point of the roof.

56. The dial that shews the points of the compass, or the cross rods that shew the cardinal points (on a common vane), must be set truly, by the aid of an azimuth compass, to true (not magnetic) north.

57. *Setting up the 2-wheel anemometer.*—Screw the piece of gas pipe, which serves to carry the instrument, on an iron rod firmly bedded in brickwork, or clamp it to a stout post firmly fixed on the roof of the house; then screw on the dial box. It must be at a considerable height (not less than 20 or 30 feet) above the ground.

58. Before fixing the cup frame in place, unscrew and remove the brass nut, and the brass column on the top of the dial box. Oil the upper part of the spindle thoroughly, then replace the brass column, and screw it home. Place the cup frame on the spindle, so that when moving with the wind, the figures 1, 2, 3, 4, 5, on the *inner* scale of the dial, pass in that order under the fixed pointer.

59. *Setting up the 5-wheel anemometer.*—Procure a piece of wood 4 or 5 feet in length and 4 inches square, with one end planed, smooth and level. Secure it by strong iron clamps, in an upright position, to the brickwork of the parapet or wall of the observatory, and with the end at a proper height above the roof, and level (Rule 55). Screw the dial box of the anemometer on the smooth end, and further secure it by iron clamps over the flange. It must be not less than 20 feet above the ground.

60. Before fixing the cup frame, unscrew and remove the brass nut from the spindle, and the brass column on the top of the dial box; oil the upper part of the spindle thoroughly. Replace the brass column, and screw it home. Place the cup frame on the spindle in such a manner that, when set in motion by the wind, the figures on the several dials may pass beneath the pointers in their proper order, 1, 2, 3, &c.

61. *Reading the anemometer.*—For full directions, see §§ 92 and 94.

62. *Oiling.*—Oil the working parts of the vane, about once a month, with neatsfoot oil, but add the oil sparingly, leaving no excess to take

up dust, and clog the bearings. If neatsfoot oil be not procurable, poppy, sesamum or olive oil may be used, not mustard, castor or cocoa-nut oil.

63. *Estimating wind force.*—At stations unprovided with an anemometer, the force of the wind is to be estimated and recorded in numbers, 1 to 6, as follows:—

Light wind	... ...	No. 1 = 1 lbs.	pressure.
Moderate	... ...	„ 2 = 4 lb.	„
Fresh	... ...	„ 3 = 9 lbs.	„
Strong	... ...	„ 4 = 16 lbs.	„
Heavy	... ...	„ 5 = 25 lbs.	„
Violent (hurricane)	...	„ 6 = 36 lbs.	„

CLOUD AND WEATHER OBSERVATIONS.

64. *Clouds.*—Estimate the proportion of clear, unclouded sky visible in tenths of the entire expanse. An unclouded sky is '0,' one entirely overcast is '10' [§ 99]. Omit from the estimate clouds low down, near the horizon.

65. Notice the kinds of clouds visible [§§ 100—107] and the direction of their motion [§ 110], also, when possible, their rate of movement [§ 110]. If those at different elevations are moving from different quarters, observe both, and write them down thus, indicating the compass point by the figures given in § 83:

$$\text{“}\frac{\text{C k. from 6.}}{\text{K. from 18.}}\text{”}$$

66. *Weather symbols, &c.*—Learn the use of the weather initials and symbols, and use them intelligently to describe what is observed. Expressions descriptive of the personal feelings, such as "close," "sultry," "cool," "pleasant," &c., are of no value.

67. These observations should be made in the intervals of the regular hours of reading the instruments, and the hour to which the observation refers is to be noted. The hours of rainfall, of thunder storms, dust storms or hail, &c., are to be noted against the appropriate symbols.

68. The occurrence of dew on the herbage, or fog in the early morning should always be noticed and entered in the register.

REGISTERS.

69. *Registers.*—Two forms are used for registering. The smaller, termed the "observer's" form B, is for writing down the observations as made without reduction or correction. The larger, termed the "record" form A, is for reduced and corrected observations, and the calculated means. For filling these, see §§ 148,149.

70. The observer's form (B) contains columns for 8 days. A new form is to be commenced on the 1st and 15th of each month.

71. Be careful to enter the name of the station at the top of each form, and in the first column the distinctive numbers of all the instruments in use.

72. Form A contains the observations of one month. The information required in the headings of the form and in those of the several columns is never to be omitted.

73. Neat and distinct handwriting is indispensable in filling the forms.

TELEGRAMS.

74. *Time of despatch.*—Stations which send daily one telegram only, which contains the report of two sets of observations, should despatch it as soon as possible after 10h.; stations which telegraph twice daily, as soon as possible after 10h. and 16h.

75. *Contents of telegram.*—Each telegram will consist of the date and hour, three groups of figures and their doubles, giving the instrumental readings, and *brief* verbal reports or weather initials, as follow:

The first group consists of the barometer reading *to two places of decimals,* and with the first figure (always 2 or 3) omitted, and the reading of the attached thermometer making five figures in all.

The second group will consist of the reading of the dry-bulb thermometer, omitting decimals (two figures), the difference of it and the wet bulb (one or two figures), and the rainfall since the previous telegraphic report in inches and tenths (two figures), omitting the smaller decimals. If there be no rain, put " 00."

The third group will consist of the direction of the wind (always consisting of two figures, with a " 0 " before the figure if it be less than 10 (=E. S. E.), its velocity in miles per hour (also always two figures, and three figures if the velocity amounts to 10 miles or more), or, in the absence of an anemometer, the estimated force of the wind (one figure), and the direction from which the clouds are moving (two figures). If there be no cloud, these two figures will be cyphers.

76. Remarks are to be telegraphed in the initial letters [§ 112], as far as possible, and are in all cases to be as brief as possible.

77. The following is given as a specimen of a telegram, together with the interpretation:—

Telegram.

716 ...	97688 ...	half ...	195376
	901000 ...	„ ...	1802000
	2411800 ...	„ ...	4823600
		c.	
810 ...	98085 ...	half ...	196170
	87301 ...	„ ...	174602
	202616 ...	„ ...	405232
		c. v.	

Interpretation.

Date	7th	8th
Hour	16h	10h
Barometer...	29·76	29·08
Attached thermometer... ...	88	85
Thermometer, dry bulb ...	90	87
Difference (wet and dry) ...	10	3
Rainfall	0·0	0·1
Wind direction	W.	S.W.
Wind movement, miles per hour ...	11·8	2·6
Cloud direction	0·0	S.
Weather initials	*c.*	*c.v.*

RULES FOR HOURLY OBSERVATIONS.

1. These are to be recorded on four days in each month, *viz.*, the 7th, 14th, 21st, and 28th.

2. The first set of observations to be taken at midnight of the 6th, 13th, &c., and to be repeated every hour thereafter till midnight of 7th, 14th, &c. Each series will, therefore, consist of 25 sets of observations.

3. All the instruments are to be observed, except that the self-registering maximum thermometers[a] are not to be registered between 16h. and sunrise on the following morning, nor the minimum self-registering thermometers between sunrise and the following sunset.

4. Special forms will be supplied for entering the observations.

5. The superintending officer in charge should allot the hours of observation between the two observers, not leaving the division to their discretion or mutual understanding. The hours from midnight to sunrise, and sunset to midnight, should be divided in such a manner that neither observer shall be on duty for more than 3 hours continuously. Thus, if observer A. begins the series at midnight, he is to call B. at 3h., and the 3h. set will be taken by the two together; B. will then remain on duty till 6h. In like manner, after 18h. one observer will be on duty from 18h. to 21h., and the other from 21h. to midnight.

6. In order that there may be no difficulty in tracing false or erroneous entries home to the observer at fault, each observer is to initial the observations for which he is responsible.

7. If, by accident, a set of observations has been missed, the observer is on no account to attempt to interpolate them. Any attempt to do so will subject the observer to fine or dismissal.

8. All the maximum thermometers, including that for solar radiation,[a] are to be observed with the other instruments from sunrise until they reach their maximum.

9. All minimum thermometers, including that for grass radiation, are to be read every hour as ordinary thermometers between sunset and sunrise.

[a] At observatories that are supplied with a non-registering solar thermometer, the sun observations are to be recorded hourly from sunrise to sunset.